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Journal
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The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 220 JULY, 1935 No. 1

THE END OF AN ERA.*

BY

L. K. SILLCOX,

Vice President,

The New York Airbrake Company.

1. To all who view the present situation in our national transportation system without the understanding which comes only from intimate contact with the industry itself, there appears an irrational confusion involving railways, trucks, pipelines, waterways, and airways. The layman is bewildered by reports of new equipment types, speed records, railway consolidations, government regulation of transportation, store door collection and delivery, damage to highways, and federal appropriations to support favored transport. It is difficult for him to visualize a coördinated system. He is impressed by the perpetual stream of accusations, emanating from within the ranks of each transport agency and directed toward the operations of each of its rivals. There is little reason to wonder that the public is unsympathetic toward its basic utility. Many interests are involved, jealous of progress which threatens to divert personal profits or at least to demand a more vigorous effort to secure an attractive balance sheet. It requires genius and clear thinking to picture the future of transport conducted along well ordered lines, coordinating the services of the manifold interests which are now engaged in harmful practices and destructive competi-

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tion, and to prophesy the manner in which each may improve, not only its own plan of operation, but its plant as well, in order that the public, always dependent upon the excellence of its transportation system for civic well being, may enjoy new standards of comforts, education, and personal freedom.

2. It has never been possible to maintain independent and competing agencies of transport on a level of parity, devising a system of equalization which will remove the influence of the natural advantages peculiar to any one participant. It is neither possible nor is it desirable that such a plan be entirely accomplished. Leadership is required for the conduct of a single purpose and, when the purpose is that of furnishing the finest system of national transportation service which it is possible to develop, it is apparent that the coördinated scheme must be directed by a central authority, commanding a common interest. In the present situation, such leadership exists, educated in the conduct of mass transportation and exercising authority over the operation of the country's basic transportation system—the railways. It is not by chance that the railways have gained their position of prominence and that railway operations are carried on with harmony and a high degree of helpful coöperation. The futility of reckless competition has been demonstrated by the costly process of trial and error and the railways, reminiscent of their own early struggles, are apprehensive of the future unless, by the subordination of selfish motives to the real needs of the present, all interests now involved in the transport of available traffic respect the terms of a carefully conceived program which will define and assign the functions of each. Such a plan has yet to be developed. Only the fact that the railways must occupy the central position, forming the nucleus about which the other carriers must group themselves, can be established with confidence. They alone have had the benefit of an hundred years experience with traffic problems. They alone have the organization and plant capable of administering so great an undertaking. They alone are indispensable to the economic security of the country. Mindful of their own errors, they can vision the future of transport more accurately than can one whose individualism might over-shadow the many intricate practical details which must be considered.

3. Much of the prejudice with which railways have been and are still regarded comes in a straight line from the forebodings that so fiercely opposed changing the Cumberland highway to a railway. One may read in the faded pages of the Congressional Record how that foreboding expressed itself. Railways were undemocratic; they were vehicles for absorbing the interest and wealth of aristocrats to serve themselves. As for the common people—what they wanted and would have was a road on which they could all travel together, freely and sociably: nothing exclusive; no tolls; no monopoly—a people's road. Regardless of the narrowness of such a view, it foretold an economic truth together with its political consequences when neither the truth nor its consequences had been foreseen. A railway was bound to be a monopoly in spite of the fact that competition was then believed to be the perfect and durable safeguard against it. Yet competition, as in time was learned, tends straight toward monopoly—its first term is survival of the fittest.

4. When the railways began to consolidate into reasonably extensive groups, fear of monopoly was suddenly very active, resulting in laws being enacted to avoid such procedure. Great systems already formed were broken up if the various sections of which they were comprised had been competitive before. The gathering together of many disjointed lines into one well-related transport machine represented nothing economically undesirable. It did, however, signify a consolidation of private power, which was the power of life and death over communities, industries, and areas, and that was the issue at stake.

5. As time progressed, competition in rates became intolerable for economic reasons alone—everyone appreciated that freight rates should be uniform and stable. Then it was that rates began to be regulated, first by states and then by the Federal Government. That, naturally, was the end of competitive rates. Competition in service took its place and ultimately had the same effect as competition in rates—also, there was discrimination in service, only more concealed, and vastly harder to stop than the former juggling of rates. So at last it became necessary in the public interest to regulate service as well. Then, for the first time, it was genuinely

clear that a railway really was a monopoly since it could not very well be anything else.

6. The condition described is now so well appreciated that the Government itself proposes a scheme of wholesale consolidations, the strong lines being arranged to gather to themselves the weaker roads, and all performing uniform service at uniform rates under the common control of the Interstate Commerce Commission.

7. One of the early rate wars was precipitated by three competing railways, struggling for eastbound export traffic, made up of grain, flour and meat that went abroad in ships. Involved in that struggle, the genius of it in fact, was the strife of a number of eastern seaboard cities: New York enjoyed the major share of the export trade; Philadelphia and Baltimore contended to improve their position in regard to the traffic. The present New York Central System serving New York, The Pennsylvania Railroad operating into Philadelphia, and the Baltimore and Ohio Railroad to Baltimore; all had to compose the competition of the low rate water route from Chicago to New York via the Great Lakes and the Erie Canal. In due course the rail rate was reduced below that of the water route and such a condition would have become drastically embarrassing to the railways were it not for the fact that a large volume of profitable intermediate, or domestic traffic, as distinct from export traffic, was moved. It bore higher rates and was the genesis of the low through rate which may be termed a wholesale rate as compared to the higher local rate for shorter distances between non-competitive points. In due course the Baltimore and Ohio, as the junior party and most aggressive agent to the controversy, secured from the New York Central System an agreement to maintain rates from Chicago to New York no lower than the rates from Chicago to Baltimore. The Pennsylvania participated in this arrangement. So it was that, regardless of distance, the three cities involved were placed upon a uniform basis in so far as rates charged on export traffic from Chicago was concerned. Following this, it was realized that ocean rates to foreign ports were lower from New York than the same service from either of the other two cities thus resulting in still maintaining the advantage

for New York. Since the parties to the struggle had already agreed to compose their differences and because none of them could possibly control the ocean rates, it became immediately necessary for the New York Central people to agree to hold their all-rail Chicago to New York export rate at a level which would offset the differential in ocean rates operating against Philadelphia and Baltimore and only in this way was a replacing of the previous rate war avoided. Here we have the spectacle of the railways giving lower rates than the all-water route from the West to the seaboard, resulting in the Erie Canal failing to give New York City the advantage which the state had spent vast sums to produce and, in addition, attempted to maintain but without avail.

8. It is well to bear in mind that the same general situation still holds in spite of the fact that the fixing of rates has become strictly a function of the federal government and presumably because a better or more practical compromise could not be derived.

9. The principal eastern seaboard traffic centres had no sooner composed their differences than they were required to contend with a movement covering the deflection of tonnage to Gulf Coast ports. Railway lines were hastily projected and cheaply built to reach New Orleans, Mobile, Houston, Port Arthur, Galveston and other ports. It has always been realized that a ship reaching a port brings in a cargo and reciprocally carries tonnage outbound, thus generating import business by the same means as export traffic is built up. With the better organization and greater resourcefulness, coupled with the superior facilities and equipment at their command which was well adapted to handle tonnage economically, the older eastern seaboard lines were in a position to name rates such as would contrive to attract the available export business moving east to the North Atlantic seaboard rather than permit it to be diverted to Gulf Coast ports. The communities involved responded in an encouraging manner, so much so that the resultant effect on established practice was profound. For example, the rate for grain products from the west to the Atlantic seaboard was 47 per cent. less if destined for export as compared with domestic use; the charge on packing house products proved to be 47½

per cent. less, the difference in both cases being sufficient to allow the commodities to move to foreign ports and return and still undersell the product which had moved directly to the point of domestic consumption. In another sense, it pictures how cheaply our products were being supplied to foreign trade centres compared with points of home consumption, thus giving an unfair trade advantage on the basis of the influence it had on the cost of living in favor of competing foreign manufacturing communities, making it possible for them to supply their labor at lower wages by reason of the relative cheapness of the food supplies made available in this manner. This was not a problem of the domestic rates from Chicago to the eastern seaboard being too high, but rather the export rates were too low, so much so that it comprised a question of whether such low priced transport of our natural resources to foreign nations did not, in effect, represent an outright subsidy to foreign manufacturers. In the reverse movement other consequences were met, especially as regards efforts to stimulate return westbound import traffic, which resulted in applying such low tariffs as to enable western merchants who were most advantageously located with respect to a live and continually expanding marketing area, and thus in a position to take advantage of every price differential arising from quantity purchases, to import goods direct from abroad in carload lots, which they did. This had the natural effect of replacing the eastern import jobber as supplier to the nation, who in turn realized that much of this thriving jobbing business had come to be centered far inland by reason of the struggle to hold export traffic in the North Atlantic seaboard.

10. The thought of national transport had to evolve. Even down to the Civil War there was only one railway company that owned and operated more than 200 miles of continuous railway. People were not yet nationally minded. We may ask ourselves what New England has in common with Texas. Here we have an intensely industrialized section, set off by itself, fabricating cloth and metal goods with neither fuel nor any of the necessary raw materials within its borders. Its industries could not continue, its population could not survive, were it not for admittedly low freight

rates on raw materials from the South and West. Such rates are not distributed among participating lines on a strictly mileage basis. A special portion of the total through freight rate from the far distant cotton fields, coal mines, and steel mills accrues to the terminal lines of New England which, although responsible for a very small proportion of the total haul, are required to provide costly terminal and side track facilities in congested areas, bearing high rates of taxation. There is a large measure of justice in rate schedules which the Interstate Commerce Commission, in whose power it is to say how the earnings from a joint through rate shall be divided among the several participating lines, has fixed. About ten years ago, it ordered that the share of New England roads should be advanced 15 per cent. Systems carrying freight long distances to the point at which New England railways receive it, were thus obliged to accept less for their share of the work in order that the New England lines, New England industries, and, in fact, New England itself, might be saved. Were it not for these practices, the remote sections of our land, with their naturally diverse interests, might never have coalesced. They did, as a matter of fact, only with great difficulty. This step having been taken, the whole could reasonably become broken up again if the tremendous binding power of low freight rates, regulated by Federal authority and based on a consideration of earnings as a whole from a composed National transport scheme, is not maintained, knowing that its influence causes commerce to cross and re-cross, irrespective of natural barriers or distances. Throughout all this process of modification and adjustment which adheres to no inflexible formula, there has been witnessed the influence of practical forces, quietly operative in the interest of equality of treatment for all, irrespective of geographical location or the power and size of the individual enterprises served. There emerged a state of healthful coöperation wherein every industry might know the effect of transportation costs upon the marketability of its products in competition with those originating from all quarters of the land. Any element which may be introduced to disturb such orderly practice cannot remain unchallenged and the attitude of railways and responsible industries alike in opposing un-

regulated highway and waterway competition which, in a few short years, has gone far toward the undoing of the creditable work of years of untiring effort in the establishment of equitable tariffs, is entirely justifiable.

11. Universal, cheap transport as an element of national good was, for a long time, obscured by provincial consideration. People at either end of a long, inland route enjoyed very low freight rates whereas those situated at intermediate points paid more. In this way, the famous long-and-short-haul controversy arose. Those who paid more for a short haul than others paid for a long haul of the same commodity, in the same direction, on the same railway, simply could not be cried down. In other words, how could we claim that it was reasonable that the inland people of Spokane should be charged the rate from Chicago to the coast city of Seattle plus the local rate back from Seattle to Spokane, as if their freight actually went through Spokane to the coast and back again on the same rails, which naturally it did not? Such situations were very hard to explain and when specifically applied, could not be justified rationally. Two principles were in conflict—one local, one national, both reasonable. There is no justification for a transcontinental railway line as such unless it effectively ties San Francisco to New York or Seattle to Boston by inland through routes that can outmaster the water routes. To surmount them in point of time is not sufficient, the railways must at least match them in cost. This means very low rates and a large volume of traffic moving in trainload lots across the land. The plan has always been, if the traffic were secured, to have the sum of the low rate on through business on large volume shipments and the higher rate on intermediate or low volume traffic together carry the operating necessities of the property. If freight rates were strictly adjusted according to distance, the industries of the East would be ruined because they could not possibly reach the West with their goods—the cost of transporting them would be prohibitive. This, in turn, would affect the West to its own great disadvantage since this section is agricultural and sends its surplus east, just as the East is industrial and ships its goods west.

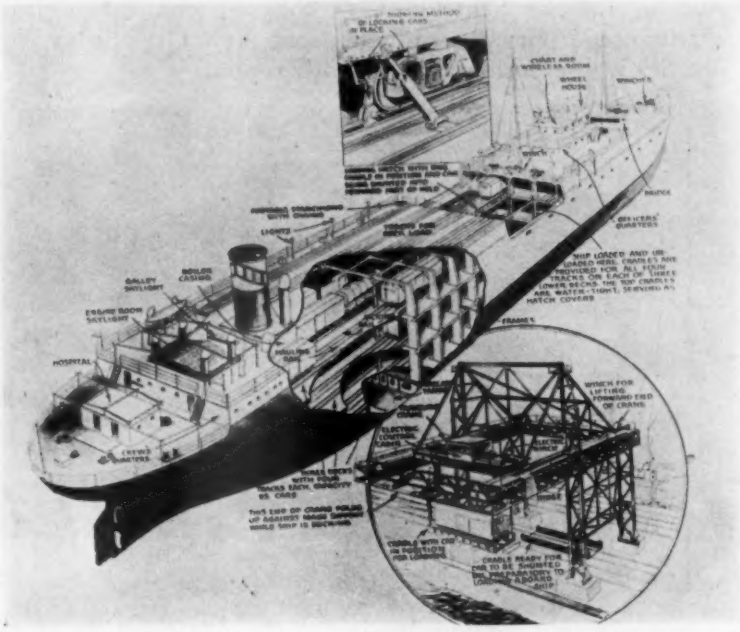
12. Singularly enough, when the Federal Government began to regulate freight rates, one of the very first items written into the law was the long-and-short-haul clause, forbidding railways to charge more for a short haul than for a longer one of the same character and in the same direction. There was a wise provision made, however, to the effect that the Interstate Commerce Commission could, under their authority, make exceptions. This was obviously necessary if everyone in business were to continue in his established way. It meant that such freight rates, reasonable or unreasonable, should be maintained as would tend to abolish distance and to level the planes of trade. It is clear then that, had the railway rate structure been technically developed from the beginning, the development of our country would surely have been very different than it has been. It is well to remember that Charles Francis Adams, Jr. said that farming had gone too far west. The precise explanation resided in the fact that the West could not consume its own produce. The East did not require the surplus. The cost of transporting it to seaboard for sale abroad, supposing it were wanted there, was prohibitive. In such circumstances, either the East would have to bodily move west with its cities and industries to save the West or the West would have to come back east to survive at all. Whereas either scheme was logical, still neither was feasible. As it worked out, the fate of the West was not in the hands of rational executives nor influenced by technique; it was in the hands of men who, when they saw the West burning corn for fuel and mountains of wheat rotting on the ground, argued, 'this is potential traffic, there is someone to buy it if we can move it and do so cheaply.' So it was that the genuine wholesale idea of transport by rail was fully appreciated since this was a task of moving grain and foodstuffs half way across a continent to tide-water at a cost that would not operate against a market for the commodities handled. It was solved by evolving the character of railway with which such tonnage could be moved at the least cost—dictating the use of larger cars, more powerful locomotives, heavier rail, and stronger track structure throughout, to accommodate the larger and heavier loads

to be carried, all in order to increase the trainload and observe the principle of producing mass transport on rails.

13. Such reasoning brings us face to face with the plain truth that any surplus of usable material, manufactured product or human labor which cannot be employed locally, has no value unless it can form contact with a market. The mechanic in a small town in close proximity to a large employment centre may have no local value in his latent capabilities. The first value his services could acquire would be by being placed in the channel of employment and its importance would depend upon the character and the cost of the transportation service he could command to and from his prospective point of labor. Whether it is labor or material, the first value it acquires is that secured by placing it in line for use. When transportation is considered in this way, as an organized medium, privately operated, where place value is conferred upon persons, things, communities and areas, we begin to appreciate something of the value of the so-called transport problem as being far more than a statement of economic facts.

14. The present rate structure was built up for the obvious purposes of encouraging the mass transport of low rate commodities, equalizing the opportunities of cities, states and territories, eliminating discrimination, and assuring the railways a reasonable income, at least during periods of normal prosperity. Unless some such carefully conceived plan is respected,—unless charges are equitably apportioned—the great mass of our national tonnage must be frozen at its point of origin, since commodities of low weight-value, coal, ore, cement, and forest products, constitute the bulk of railway tonnage. Such a condition could not be tolerated in view of the progress which is marked in national development and this being true, it is essential that commodities of inherently high intrinsic value bear a rate which will permit the movement of tonnage which falls within lower rate classifications and those carrying the low rate traffic must be protected to the extent of enjoying their just share of the higher paying traffic in order to properly compensate them for services rendered, otherwise, the low rates accorded the heavy volume traffic could not continue and, if this condition obtained, the

traffic could never move at all under a higher rate range. Under competitive conditions as they now exist, the cumbersome and intricate schedule of railway rates has been a factor of which nearly every competitive transport agency has taken advantage. The high rail rates borne by certain commodities have given the trucks the opportunity to operate profitably, still quoting rates to shippers lower than those which the railways themselves are powerless to modify. Inflexible



tariffs also have the effect of diverting tonnage in other directions where total costs are unquestionably higher yet lower rates can be quoted and a profit realized. The Seatrain well illustrates the extent to which rates influence the channels in which commerce moves and, as in this case, the fact that the inability of railways to fix rates strictly upon the cost of transportation, frequently originates a competitive carrier which, free from such restrictions, is successful in diverting railway tonnage.

15. The Seatrain is a specially equipped freighter, operated in coastal service between Gulf ports and New York via Havana. With approximately one mile of track laid on four decks, it can accommodate one hundred standard freight cars, the transfer of cars being effected by slinging them to or from the shore upon a short section of track. A full complement of one hundred cars can be unloaded and another hundred cars taken aboard with a minimum force in approximately ten hours and herein resides the principal advantage of the Seatrain over conventional cargo ships. Its advantage over the railhaul from New Orleans to New York lies in the permissible rate differential.

Seatrain New York.

16. Obtaining federal funds for the construction of the vessels, Seatrain Lines, Inc. were to engage in foreign commerce and, by including Havana in the coastwise trip, this requirement is fulfilled although a full cargo may move between points on the continent. Rates may be quoted which will, with a revenue load of approximately 2000 tons, pay all costs and show a net return. The same tonnage might be transported by rail in a single train, manned by five men, in shorter time. The hydraulic resistance of such a vessel is about the same as the resistance to be overcome by rail but power is more efficiently transmitted to propel a locomotive.

There are then, three major factors favorable to transport by rail; the personnel required, the distances to be covered, and the number of horsepower hours needed to complete the movement. On the other hand, the Seatrain has the advantage of a right of way furnished cost free.

17. While it is certain that the railways could handle with profit all the tonnage moving by Seatrain, quoting the same rate for through movement, still the rate might not be sufficiently high to carry a pro rated share of fixed charges on a revenue ton mile basis. A long haul full trainload rate would be essential and the operation of the long-and-short-

Seatrain Loading Operation.

haul clause militiates against the opportunity of the railways to combat competition of this nature even though every practical consideration points toward their ability to perform the same service at a lower operating cost. It is, moreover, difficult to understand the attitude of shippers who, critical of every delay to which their goods are subjected when transported by rail, are willing to await the assembling of sufficient tonnage to constitute the maximum load or 100 cars and the arrival of a ship before the journey by water is even started.

18. The function of transportation is extremely complex. The manner in which transport service is performed must necessarily be determined by impersonal principles, despite

the fact that everyone's final relation to it is personal and selfish because conditions of livelihood, profit, success, wealth, and comfort are intimately affected and, as to these, one is more likely to be human than to be reasonable. There is no transport problem in the singular—each comprises national, sectional, and individual interests, all of which are in a state of perpetual and healthy conflict.

19. The sequence of events which, in a single instance, has first resulted in intricate rate schedules; second, has brought down upon the rail carriers involved, a temporary condition which threatened to ruin them; third, has had a wide and powerful influence on markets and the distribution of goods; and fourth, has been accompanied by reactions, national in scope, has added measurably to the sum total of railway knowledge and experience and has tempered railway judgment in dealing with proposals of revolutionary character. The railways are, in consequence, admirably fitted for the newer and larger task of directing the conduct of a rationalized national transportation system which will coördinate the activities of every carrier, whether transport be by rail, highway, waterway, air, or pipeline. Furthermore, the strength of railway organization and the integrity of railway securities must be maintained and to this end some plan for a revival of railway profits must be forthcoming which will take into account the existence of many rival carriers, on only justifiable grounds, properly correlating functions to produce a unified system.

20. The present railway situation, expressed in terms of earnings of the properties and return to investors in railway securities, is disheartening, to say the least. Selecting, for the purpose of comparison of income and traffic trends, the years 1923 and 1930, spanning an eight year period of more or less normal operation, subsequent to war time influences and prior to the disturbing consequences of the depression, figures definitely reflect the trying circumstances under which the railways are laboring. Extending the period in either direction darkens the aspect still further but it introduces factors with which the present discussion is not primarily concerned. Investment in railway properties increased over four billion dollars between 1923 and 1930, of which approxi-

mately one fourth was financed by the issuance of bonds. Additions and improvements in the railway plant witnessed during the period were required to maintain and improve facilities in a state commensurate with the demands of traffic and to effect operating economies which have since been fully justified as is indicated by the general extension of locomotive runs and the reduction of fuel demands from 163 pounds of coal per thousand gross ton miles in freight service and 18.1 pounds per passenger car mile in 1923, to 121 pounds and 14.7 pounds, respectively, in 1930, results typical of those observed in practically every branch of railway operation. During this same period, total annual operating revenues decreased from six and one quarter to five and one quarter billions of dollars, a decrease of sixteen per cent while the net railway operating income produced rates of return on railway investment of 4.33 and 3.30 per cent in 1923 and 1930 respectively (further reduced to 1.25 per cent in 1932). After meeting necessary obligations of fixed nature, there remained, in 1923, 555 million dollars, available for additions to properties, reserves, and dividends. This was reduced to 524 million dollars in 1930 (a deficit of 139 million dollars was registered in 1932 in this account). The seriousness of the situation may be more fully appreciated by directing attention to the fact that an estimated 6.6 billion dollars are invested in the railways by public and semi-public institutions, the ownership of which is distributed in accordance with the following proportions:

	Amount Invested, Millions of Dollars.	Per cent. Publicly Owned Rwy. Securities.	Per cent. of Railway Funded Debt.
Life Insurance Companies	2,600	39.4	20.4
Mutual Savings Banks	1,700	25.7	13.3
Commercial Banks	1,016	15.4	7.9
Hospitals and Religious Institutions	221	3.4	1.8
Philanthropic Foundations	200	3.0	1.6
Educational Organizations	176	2.7	1.4
Other Public or Semi-Public Agencies	687	10.4	5.4
Total	6,600	100.0	51.8

As a result of the confidence reposing in the stability and earning power of the railways, there has developed a close interrelation between the prosperity of railways and the strength of our basic financial institutions and this fact, perhaps more than any consideration of public transport requirements, present or future, has exerted a strong national influence terminating in the careful investigation of railway matters which is now in progress, conducted by a new federal authority. Any plan of reconstruction must be cautiously approached and administered in such a fashion that changes can be gradually and inoffensively introduced in view of the inevitable repercussions affecting, through these important agencies of trusteeship, every community throughout the land.

21. A further comparison of operating statistics, 1923 and 1930, indicates, in a general way, the trend of traffic, and concentrates railway attention upon certain commodities and classes of traffic which have been subject to greatest losses of railway traffic volume. It is first observed that, in 1923, the average length of haul per ton of revenue freight was 176.86 miles. By 1930 this had increased five per cent. to 185.86 miles, indicative of the fact that the short haul was suffering greatly from the inroads of truck competition. Likewise, the average revenue per ton of freight moved one mile by rail decreased from 11.16 mills in 1923 to 10.63 mills in 1930, indicating further that the highest paying traffic was being rapidly diverted from the rails to reduce the average revenue. The following figures are interesting in that, although they do not take into account variable trade conditions, they do show the commodity classifications which the railways have endeavored to retain with failing success.

Tonnage of Revenue Freight Originated by Class I Railways—Thousands of Tons.

Commodity.	1923.	1930.	Per cent. Increase (+) or Decrease (−).
Products of Agriculture	109,318	110,728	+ 1.3
Animals and Animal Products	28,254	23,129	−18.1
Products of Mines	713,735	642,537	−10.0
Products of Forests	115,618	69,371	−40.0
Manufactures and Miscellaneous	267,767	277,765	+ 3.7
All Less than Carload	44,338	29,667	−33.1
Total—All Commodities	1,279,030	1,153,197	− 9.8

The decrease in tonnage noted above is even more impressively expressed in terms of loss in revenue. By applying the average commodity rate per ton handled as of 1932, based on the revenue received for the transport of each commodity classification per originated ton, to the tonnage handled in 1923 and 1930, thereby eliminating the variable factor of rate differentials, the total equivalent loss of revenue is derived in the table below:

Revenue Accruing from Haulage of Freight on Basis of Common Rate Derived from 1932 Results.

Commodity.	1932 Level of Frt. Rev. Dollars per Originated Ton.	Equivalent Revenue—Dollars × 1000.	
		1923.	1930.
Products of Agriculture	5.94	649,349	657,724
Animals and Animal Products	10.53	297,515	243,548
Products of Mines	2.02	1,441,745	1,297,925
Products of Forests	4.12	476,346	285,808
Manufacturers and Miscellaneous	5.36	1,435,231	1,488,820
Less Carload Lots	16.59	735,567	492,175
Total—All Commodities		5,035,753	4,466,000

These two tables lend themselves to a comparison of the ratios obtaining between tonnage originated and the revenue derived in the haulage of the various commodities to the total tonnage and revenue.

Relation between Tonnage and Revenue.

Commodity.	Per cent. of Total Tonnage		Per cent. of Total Revenue.	
	1923.	1930.	1923.	1930.
Products of Agriculture	8.57	9.57	12.89	14.71
Animals and Animal Products	2.21	2.00	5.82	5.44
Products of Mines	55.78	55.53	28.64	29.10
Products of Forests	9.03	5.98	9.50	6.39
Manufacturers and Miscellaneous	20.91	24.00	28.53	33.32
Less Carload Lots	3.46	2.56	14.62	11.00

22. The tables definitely establish traffic trends and explain the longer average freight haul and the lower unit receipts. The effect of the motor truck is instantly recognized

as the factor chiefly responsible for the pronounced loss of railway tonnage witnessed in the transport of animals and animal products and less than carload freight, the two commodity classifications which command the highest per ton rate.

23. Due to lack of organization and to the number of private interests involved in the motor trucking industry which are responsible to no central authority, it has been extremely difficult to assemble data to accurately define the extent of trucking operations and such estimates as have been prepared are the results of analyses embracing but a small proportion of total truck movements. Even the most casual survey of trucking operations, however, indicates results entirely compatible with the conclusions to be derived from a study of railway data.

24. An increase of 1.3 per cent. is observed in the railway tonnage of products of agriculture. This principally reflects comparative crop and market conditions since it has been definitely established that the volume of such commodities moving by truck increased during the period 1923–1930 and to a still greater extent in subsequent years, although the effect of the motor truck was not particularly pronounced in this classification. The mass transport of agricultural products, grain, vegetables, and fruit, which are moved long distances and in carload lots, remains with the railways by virtue of the moderate rates charged, the seasonal nature of the traffic, and the inability of the truck to compete on high mileage hauls. There are regional exceptions, notably observed in the transport of fruit from the fertile apple districts of the west and the orange groves of Florida and lower California. A serious decline in the fruit traffic of railways serving these areas has been noted but the effect, while proving serious to the railways directly affected, is of local significance and does not reflect greatly on national figures. Except for some few agricultural products which require certain conditions of soil and climate in order to flourish, agricultural activities are quite uniformly distributed over the entire area of the United States and the trucking of products into the Metropolitan centres for immediate consumption represents the greatest application of highway haulage witnessed in

agriculture. This trade, however, was never productive of great railway traffic volume measured in ton miles and the influence of trucking has been chiefly instrumental in bringing about a change in the method of conducting this business. The introduction of the motor truck has had the effect of removing from city boundaries to more remote areas favored by lower tax rates, the truck farmers who before had crowded close to densely populated districts in order to avoid a long slow haul to market which was necessary before the truck was available to accelerate the daily movement. Data have been assembled, indicating the ratio of tonnage of agricultural products received by truck at seven important metropolitan markets as a proportion of the total receipts. Those are given as:

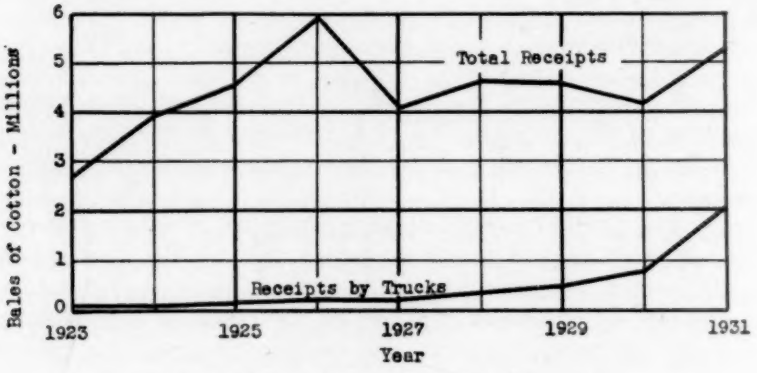
Market	Per cent. of Tonnage Received by Truck (1931).
Boston	10.9
New York	12.7
Denver	24.3
Philadelphia	27.8
San Francisco	31.7
Salt Lake City	57.7
Los Angeles	64.3

The effectiveness of the truck in this respect is a direct function of the accessibility of the market to the producing area, being further affected by the duration of the productive season.

25. As in the case of other agricultural products, except animals and animal products which fall within a separate and distinct classification as reported by the Interstate Commerce Commission, the use of the truck in the haulage of dairy products, poultry, and cotton, commodities which have been the subject of special investigation, has been particularly pronounced in most recent years and the selected period, 1923–1930, does not reflect the full force of truck competition with which the railways are now confronted in the transport of these commodities. The trend is based upon records maintained at certain scattered markets and is subject to modification if complete data were available. Due to the fact that with trucks available to redistribute goods from central markets to outlying points and the growing tendency

to effect wide distribution in this manner, it is likely that complete detailed figures would show relatively greater diversions of railway tonnage. In this connection, the chart below which indicates the relation of cotton receipts by truck to the total at the important markets, Memphis and Galveston, is interesting and enlightening. Equivalent figures for like period at other markets or pertaining to other commodities are not available.

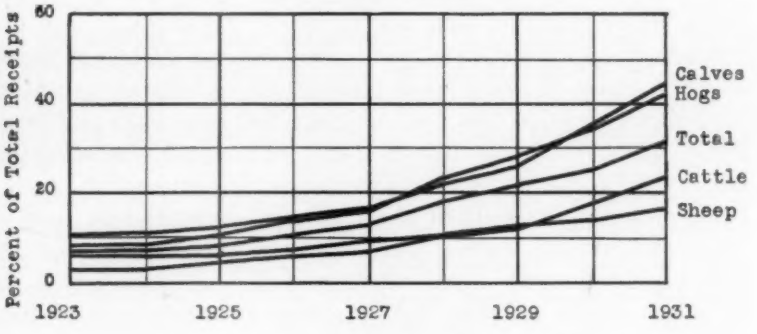
26. In the handling of animals and animal products, the motor truck has made more rapid advance than in other products of agriculture. The reasons are readily attributed to the high rate which this traffic bears, the perishable nature of the traffic which requires prompt transport and costly servicing en route, the existence of an all year market, and the erratic market conditions which make it particularly desirable that deliveries be effected promptly at the most opportune time. Much of the livestock haulage is done in the farmer owned truck, although the contract trucker,



Cotton Receipts at Markets of Galveston and Memphis.

serving either farming communities or livestock jobber, is active in this field. Rates quoted by contract truckers are invariably lower than rail schedules; shrinkage is found to be a relatively constant factor whether livestock is moved by truck or rail; and the railway appears to offer some slight advantage in regard to the crippling of animals in transit. The governing factors, however, are the ultimate cost of the

service, the relative convenience and availability, together with the total time required in effecting deliveries. The present practice observed in the packing industry of establishing local branches in producing territories, thereby decreasing the length of haul, has also been an important factor favorable to livestock trucking. The proximity of producing areas to central markets is the controlling factor in the determination of the extent of truck competition with railways as is clearly shown by the chart on the preceding page, indicating the relative rate of introduction of truck use in this service, variable with the type of product. Thus, sheep and cattle, largely raised on ranges more or less remote from



Livestock Receipts by Truck at 16 Important U. S. Markets.

markets and requiring longer hauls, have not been subject to trucking activities to the same extent as have calves and hogs, originating in more concentrated districts, convenient to packing houses.

27. Thus it is that industry has, in some instances and notably that of the packing industry, allied itself with the trucking interests to maintain rail traffic of certain commodities at new low levels. Decentralization is in progress in these lines. The stock yard receipts are no longer an accurate index of traffic results since the large central stock yards do not receive the proportion of total animals which have, for many years, passed through them. The transport element is an important factor and where trucking can be shown to be much more economical or convenient, and where

fluctuating market conditions create urgent and immediate demands, industry is cooperating with producers to increase its effectiveness.

28. The fact that railway traffic in products of mines and forests suffered losses of 10 and 40 per cent., respectively, when the traffic of the year 1930 is compared with that of 1923, is due less to the diversion of these heavy, long haul, low rate products than to economic conditions since, with the sudden collapse of security values in October 1929, a like depression in the demand for products of mine and forest was immediately felt. Trucking was instrumental, to some extent, in reducing rail tonnage, especially in consumer distribution and where return loads were involved for trucks regularly engaged in one way traffic. Additional pipe line mileage transports natural gas to replace coal and fuel oil and gasoline move through pipe lines to an increasing extent to reduce rail tonnage, but the fact that, between 1929 and 1930, decreases of nearly one hundred million tons of mine products and 25 million tons of forest products, approximately 13 per cent, and 22 per cent. of the tonnage originated in 1923 in these two classifications, were witnessed, indicates that the depressed tonnage was less the result of conditions which the railways might combat than natural processes over which they had no control.

29. In the transport of manufactured products, railway tonnage has continued to increase in spite of the fact that much of this traffic now moves on the highways and over inland water routes. In this connection, one should not overlook the fact that, while commercial trucks continue to obtain an ever greater annual tonnage of merchandise which in past years would have been entirely rail borne, the automotive industry has, at the same time, contributed greatly to the tonnage offered the railways, both in raw materials traveling routes which converge at the great automotive manufacturing centers and, to a less extent, in the distribution of assembled units. According to claims of the National Automobile Chamber of Commerce following their investigation, the automotive industry originated, in 1931, 410,845

carloads of railway freight including automobiles, trucks, tires, and parts, or a total of over three million carloads of all products including all raw materials required for automobile manufacture, gasoline, and materials required for highway improvement.

30. In the handling of freight offered for transport in less than carload lots, the common carrier truck finds the service for which it is best adapted and that which it can most profitably perform. It offers, with its characteristic pick-up and delivery service and minimum handling, quick and convenient accommodation to shippers where the length of haul does not exceed 100 miles and a large proportion of all l.c.l. shipments fall within this range. There is scant justification for opposition to the diversion of this branch of railway service since it must be acknowledged that the truck, in almost all cases, is prepared to furnish superior service and can do so at a lower total cost. A single transfer of lading generally introduces 24 hours delay by rail, whereas the motor truck can reach any number of off line points without transfer or reclassification. Where two or more connecting truck lines cooperate to complete a road haul, the transfer is a simple operation, effected from one truck body to another with a notation of transfer substituted for the railway duplication of way bills. The loss of one third of the tonnage which bears the highest rate of any commodity classification handled in the eight year period, 1923–1930, still further reduced to show a loss of 65 per cent. in 1932 as compared with 1923, has been a cause of grave concern to the railways, but there appears to be little prospect of their obtaining this traffic except by the installation of a coöperative plan, employing trucks to operate in conjunction with the rail line haul and even then, only l.c.l. transport involving a single rail operation or a distance of over 100 miles can well be anticipated as ultimately returning to the rails.

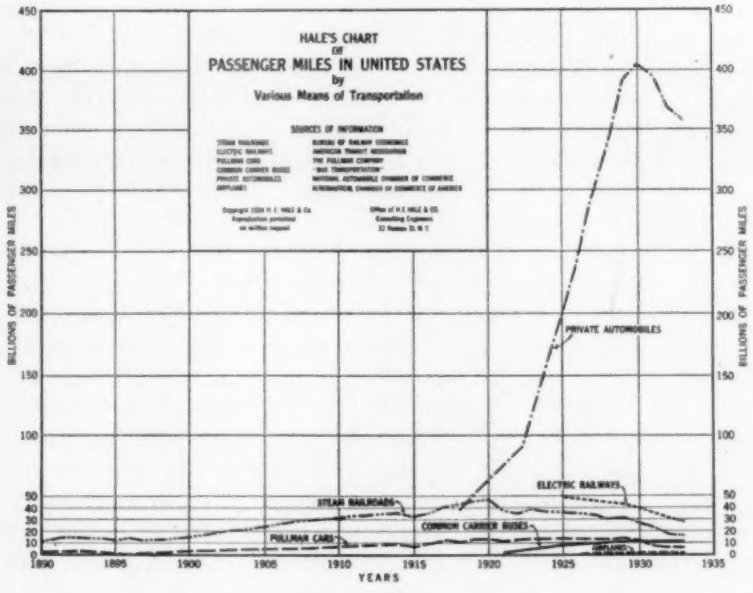
31. A review of railway passenger statistics is even more depressing to those responsible for railway profits. From 1920 through 1932, passenger traffic data afford the following comparisons:

Passenger Traffic Data—Class I Railways.

Year	Passenger Miles-Billions.	Revenue Per Passenger Mile-Cents.	Passenger Car Miles Millions.	Total Passenger Train Revenue Dollars × 10^6.
1920	46.8	2.75	3,583	1,636
1921	37.3	3.09	3,469	1,408
1922	35.5	3.03	3,414	1,365
1923	38.0	3.02	3,585	1,452
1924	36.1	2.98	3,646	1,378
1925	35.9	2.94	3,746	1,360
1926	35.5	2.94	3,837	1,351
1927	33.6	2.90	3,831	1,277
1928	31.6	2.85	3,799	1,209
1929	31.1	2.81	3,857	1,232
1930	26.8	2.72	3,680	1,006
1931	21.9	2.51	3,266	780
1932	17.0	2.22	2,736	560

Between the years 1923 and 1930, a shrinkage of 30.7 per cent. in revenue derived from passenger train operation was suffered by Class I railways while freight service revenues were reduced by 11.5 per cent. In 1923, passenger train revenues accounted for 24 per cent. of the total train service income, reduced to 19.8 per cent. in 1930. While the greater proportionate loss was suffered in passenger traffic and revenues, the decrease in freight tonnage moving by rail is the cause for greater concern by virtue of its relatively greater contribution to railway gross income. There is one feature, however, of passenger train operations which is particularly prominent and which has proven especially burdensome, combating every effort of railway administrations to maintain a reasonable balance between passenger train expenses and revenues. It is found in the fact that, while 30.7 per cent. loss was suffered in passenger revenues between 1923 and 1930 (or 61.3 per cent. if the 10 year period 1923–1932 is taken), the cost of conducting the service, measured by the passenger train car miles operated, actually increased 2.65 per cent. (a decrease of 23.6 per cent. was effected in 1932 as compared with 1923). It is evident, as judged by this record, that the railways are hauling poorly patronized accommodations in passenger service and that a marked traffic increase could be handled without involving the railways in any additional expense for train operation.

32. As disclosed by the accompanying chart, the total volume of passenger traffic of the United States assumed its maximum level in 1930 when private automobiles produced a total number of passenger miles more than four times the combined production of steam and electric railways, buses, and airplanes. Compared with the private automobile, other carriers competing with the railways are impotent agencies and the service performed by the private automobile is of such a nature that its operation is most difficult to combat by any common carrier agency. Buses do not offer a similar problem.



In 1930 there were approximately 25,000 common carrier buses in service in the United States, engaged in intercity transport, both interstate and intrastate, and those buses produced approximately 7 billions of passenger miles in competition with other carriers. This compares with an estimate of over 400 billion passenger miles produced by privately owned automobiles.

33. With the competitive transport situation thus defined and with responsibility for the decline in railway traffic definitely allocated, the efforts of aggressive railway administrations are guided in the direction of sound policies with the prospect of stopping the rate of traffic diversion and, with the help of sound and equitable public policies, of recapturing a part of the traffic which has been lost. The immediate need may be for the adoption of vigorous competitive methods designed to minimize the natural and acquired advantages of rival transport agencies, but the ultimate plan must anticipate the consolidation of all carriers into a unified national transportation system. Uniform and equal regulation, to which all trucks, buses, commercial airplanes, inland waterways, and pipelines are subject, is essential before complete stabilization is possible within the transport industry but, in view of the tremendous problem involved and the time required to bring about such an ideal condition, the railways must, in the meantime, strive to maintain a satisfactory balance between revenues and expenses, irrespective of existing conditions of inequality of treatment which will doubtless obtain for some time to come.

34. The total efficiency of a composite transportation system will be measured by the individual efficiencies of its various participants, and efficiency in transport is measured by the cost of producing the standards of service dictated by public demand. Eventually, the activities of each method will be restricted to the service which it can perform, exhibiting the highest efficiency witnessed in the production of that service. Then the individual efficiency of each method will define its prominence in the coördinated scheme and it is in the interests of the separate carrier organizations that they scrutinize every feature of their operation to the end that they will be allotted the maximum traffic volume which they can righteously command. If motor truck operation is to be restricted to terminal areas, railways must display their ability to perform short line hauls of truck load lots as promptly, including truck collection and delivery, and at a lower cost than can the truck, unassisted, under conditions whereby the highway operator bears his just share of the total expense involved including highway construction and

maintenance. If highway buses are to retain their share of intercity transport, they must demonstrate their ability to compete with railway units most carefully selected in view of local transport requirements. If inland waterway construction is to be extended to parallel existing railway lines, it must be shown that it is able to justify its existence on a total cost basis, free from political favoritism, and if pipe-line mileage is to increase, the economy of such a practice must lend itself to an analysis indicating that the public benefits by such distribution. Were the railways permitted to quote full train load rates, it is unlikely that pipe-line mileage would have grown to its present proportions. One principle must be respected in the public interest and that is, for a given volume of available traffic, with strict specifications as to the type of service which must be realized, the total annual cost of producing the service must be a minimum. In general, it is wasteful to construct super highways along an indispensable artery of rail movement. To excavate an artificial waterway and sink a pipeline in addition can seldom be economically justified, and then, to superimpose upon these carriers, scheduled air operations, swells the total investment in transport equipment for which the public must, in the end, be responsible. The merits of each must be carefully weighed, the nature of the respective services must be given full consideration, and the balance between service and total cost assigned in the determination of the proper facilities to retain. When this is done, some railway mileage will be abandoned, new highway routes selected for high type surfacing will be more discriminately chosen, motor routes will become coöperative rather than competitive. airplanes will be operated over routes and on schedules warranted by traffic demands, and obsolete equipment types will be retired in all services. Transport cost will be minimum and service will be the finest as measured by the basic standards of stability, convenience, cost, speed, safety, comfort, and reliability. Perhaps such an optimistic view of national transportation will not be realized for many years to come. Perhaps federal regulation of private enterprise cannot effectively control individual jealousies and eliminate harmful practices, quietly active and disruptive of a well ordered plan.

Perhaps local influences will cloud the true conception of expediency in transport as long as rival interests are involved. Intricate labor problems will unquestionably arise, difficult to compose. The processes involved in the eventual attainment of this objective may well be: first, federal regulation, administered by authority vested in a single body, of all common carriers, extended in its reach to include every element which interferes with the successful operation of regulated carriers; second, the consolidation of railways to encourage economies and coöperation; third, coördination of all transport activities under the direction of the railways; and fourth, if all other plans should fail to produce service, economical transport, and profits to investors—government ownership of railways may be attempted with their subsidiary motor truck and bus operations, airways, pipelines, and waterways. In all of the above, it is essential that one appreciate the fact that the first requirement is that there be a plan of uniform and equal regulation for all carriers. Such a plan would certainly be operative under government ownership. That our own Post Office Department could not operate efficiently in the face of unregulated competition such as that which oppresses the railways today, is evident nor would government ownership tolerate competition of any form which reflected unfavorably upon the department involved.

35. The process by which the present unsettled state of transportation has been attained constitutes a natural sequence of events arising from the introduction of new transport means and assisted by certain short sighted legislative policies and economically unjustifiable appropriations. There are no sound arguments to economically support the construction of artificial waterways which experience has shown cannot operate upon the revenues which they earn. To a less extent, great federal subsidies to commercial air operations are scarcely defensible. Air traffic is deserving of stimulation—it fills a need for ultra high speed communication and experience is required for national defense—but the tremendous grants which it has received from the federal treasury have removed many problems which would have been met by the resourcefulness of air operators were they required to pay a greater share of the cost of conducting the service.

36. Compared with the older forms of transport, airways possess the important advantages of great speed and relative independence of the nature of the terrain over which they operate. Speed is often a vital consideration and commercial aircraft can readily average 125–200 miles per hour. Airplanes can make unbroken journeys over land, sea, desert, or mountains and without hindrance from lakes, swamps, or rivers. Thus the delays, inconvenience and, expense of transhipment are avoided and short direct routes can sometimes be substituted for circuitous land routes. Over dif-

ficult country, such as forest regions and mountainous districts, undeveloped spaces, tropical areas, and the snow and ice clad tracts of the North, air transport has served to reduce journey time from weeks to days or from days to hours. Air transport shows the greatest advantage where primitive forms of transport are the alternative. In such circumstances, it is possible to charge high mileage rates and, at the same time, provide an economical means of conveyance. The economic sphere of air transport is determined by its two main physical characteristics, great speed and independence of any form of prepared right of way. Its relation to other forms of trans-

port is likewise determined by these two factors and, by exploiting these advantages, air transport is gradually making a place for itself among the various means of travel. Where new territories are to be opened, the newest form of transportation will be the first to encourage colonization.

37. Trucks and buses, pipelines, and commercial airplanes, operating as common carriers, are all developments of the past fifteen years and it is only within the past decade that they have assumed strength to embarrass the railways in the mass transportation of the nation's traffic. Prior to their development, there was no dearth of transportation. Every essential transport need was satisfied. They have increased the volume of transportation to some extent but the revenues required to support large scale developments have had to be derived primarily by encroaching upon the traffic of the railways. During the early years which constituted the trial period of highway trucking, the increase in national traffic demands supplied truck tonnage and railway tonnage was substantially static. The same was true of the pipeline. Gasoline consumption was increasing so rapidly that the transport of a part of the crude oil production by pipeline did not result in a decrease in rail tonnage of petroleum products. As these rival carriers expanded their operations, motor bus and truck registrations increasing from 1,117,100 in 1921 to 3,466,303 in 1931, and pipe-line mileage in the United States increasing from 55,260 miles in 1921 to 111,160 miles in 1931, additional tonnage was required to serve them and this was obtained at the expense of railway profits. In the field of passenger transport, the influence of the passenger automobile was such as to practically eclipse the traffic diversion to buses. In the case of the latter, it has been ably demonstrated that their only appeal over moderate to long distances resides in very low rates and, where these have been practiced by the railways, principally in the South, bus transportation on principal rail routes has been effectively overcome. The private automobile, however, offers a far different problem and one more difficult of solution. As viewed by its owner, it affords a means of transportation, when carrying two or more persons, with which even the lowest bus rates cannot effectively compete when the added availability and con-

venience of the automobile are considered. This feature of cost must be met by the railways, even to the point of including transportation of the automobile itself to accommodate the patron at new low rates, if any considerable portion of the annual traffic moving by automobile is to be regained by the railway. Just how successful they may be in accomplishing this result depends upon the extent to which railways are able to put new practices into effect to reduce the costs of producing transportation, passing the benefits of advance in this direction on to the traffic and, in turn, receiving a compensating advantage in terms of added traffic volume. Since there has been no curtailment in the facilities available for traffic, measured in train miles, commensurate with the loss of patronage, it is in the unfavorable load factor experienced that the railways have suffered most. Added traffic volume, however secured, is the prime necessity in such case. The inland waterway and the airplane represent particularly favored rivals because the federal government has seen fit to insure their operation at a profit. It is doubtful that any direct competitive effort which the railways might initiate would have any marked effect upon the traffic moving in these channels and their sole effort may probably be best directed toward utilizing these agencies themselves wherever it is shown to be expedient to do so.

38. In the face of advance in transport methods carried on simultaneously along these various fronts, the railways, after disposing of the inertia of their monopolistic era, have made determined efforts to improve their technical equipment. Both old and new transport agencies have caught the infection of the new era of progress in line with the strenuous endeavor to reduce costs and increase efficiency. Such striving after lower costs and greater efficiency lies at the very root of a progressive economy and it is the moving force by which improvements are carried out. Material progress depends upon such attempts to secure maximum production at a minimum actual cost. Much discussion has recently centered around the possibilities of the coördination of the various forms of transport as a solution of this problem and much is being done to arrive at the nature, advantages, and limitations of coördination.

39. Where reduced costs and increased efficiency are in progress, the process takes two forms. There is first the tendency to substitute one type of transport for another. History shows how the canals superseded the highways for bulk freight and even for passenger movement in certain sections. This practice was followed by the railways displacing the canals; whereas now the highway is again in turn attracting traffic from the railways. In the second place, the internal economy of particular types of transport is constantly being improved. In the case of railways, for instance, under intensive outside pressure, marvelous technical improvements, such as the adaptation of automotive principles to motive power and car construction, new means of signalling and communication, improved types of brake equipment, the provision of air conditioning apparatus on passenger cars, the modern locomotive, electric traction, improved materials of construction, new methods of fabrication, especially in the case of welded assemblies to displace riveted types and cast forms, have all been tried out an are in the process of more or less widespread adoption at the present moment.

40. Progress cannot be secured without upsetting the old equilibrium and it is an outstanding fact that transitional periods are beset with tremendous, almost overwhelming, difficulties. The national transport problem of today has been especially complicated by conditions altogether outside control of the railways themselves. Economic causes have had a profound influence, especially important being the effects of trade depression in the vast tonnage producing industries, occurring at a time when the railways would, under the most favorable trade conditions, have had difficulty in retaining their traffic in passengers and merchandise. Then, too, the railways have suffered from declining coal, ore, and steel tonnage.

41. In addition to the problems arising from reduced income, the railways are confronted with an insistent public demand for better accommodation. In the first place, cheaper and better service, it is argued, would tend as an important factor in the revival of railway patronage. In the second place, recent changes in our national economic equi-

librium, such as the greater development of internal markets, have led to a demand for improved inland transport. So also have changes in social habits, e.g., the growth of the travel habit, improved minimum standards of living, and changes in fashion. Industry now operates with smaller capital and shorter credit, while fluctuations in demand have increased the tendency to carry small stocks. Thus, rapid transport facilities are relied upon to replenish inventories as necessity arises. Such a condition of affairs has led to the statement that railways are being obliged to handle three times the number of consignments per ton of traffic that were offered two decades ago.

42. When we come to appraise the standing of the railways in the competitive regime, we find the following factors of interest. Railway speeds are greater than those of highway transport except where the average is reduced by terminal, transhipment, or other delays. The speed of heavy duty highway vehicles must be limited in the interest of public safety and to prevent unbearably costly damage to the highways. In certain circumstances railways can provide direct services from the private siding of one factory to that of another, or from coal mine to port, and where such direct transit is possible, the economic advantages are supreme. Highway vehicles, except in few cases, are not well adapted for the handling of heavy bulk or long distance freight traffic, nor can they cope successfully with intensive passenger traffic. This advantage of speed is one which the railways have already partially developed and will continue to exploit to the maximum. Railways are especially well suited for the handling of bulk goods and mining products, since large volumes of business can be easily and expeditiously accommodated in a few trains. Railways are subject, in a very genuine fashion, to the economic law of decreasing costs, since the outstanding features of railway capitalization are the tremendous outlay of money necessary and the preponderance of overhead or fixed charges. From the fact that a railway requires a large capital burden, the greater part of which is fixed and invariable whatever the amount of traffic carried, it follows that costs per unit of traffic considerably decrease if the volume of business handled is advanced. The

operation of excursion trains supplies an illustration of the economy of adding to the volume of business. The extra expense of running such trains is relatively small and thus it pays well to carry passengers at very low rates, provided large numbers of passengers are attracted and the ordinary standard fare traffic is not unduly diverted to the cheaper services. Railway capital has been spent for the sake of the business as a whole and it is quite a difficult matter to allocate the cost of conveyance against any particular class of traffic, much less against selected consignments. Under these conditions, railways have always imposed differential rates for various classes of traffic. Valuable commodities such as shoes, clothing, silk, fruit and vegetables, which presumably can bear higher rates, are charged more per ton-mile than low grade traffic, such as products of mines, which may only be transported in bulk. In recent years, highway competition, by attacking the higher classes of traffic, has tended, to a great degree, to break up the conventional system of classification. In the same way, the railways have been forced to grant numerous cheap fare facilities to meet highway competition. Railways possess still another advantage beyond that of speed and their unique capacity for economically handling bulk traffic. They have an important asset in their widespread organization for the collection and distribution of traffic. They are nationwide in their ramifications.

43. Highway transport in flexible and, in consequence, a more individual type of service can be rendered than is possible with any other from of transport. The highway leads everywhere. Door-to-door services can be provided and traffic can be picked up and delivered under more diverse conditions and more easily than is possible with any other type of transport. The highway vehicle is free to go to any section of the land where business is to be had. If one route does not pay, another may be experimented with and no loss suffered such as would occur were a railway to give up a territory previously served, since, in the latter case, if the route were to prove unprofitable, the capital represented by its construction would, for the most part, be incapable of movement elsewhere, and thus the expenditure would be wasted. Highway services can be started with relatively

little capital, since the public bears the first fixed cost, and the vehicles may even be obtained on the deferred payment plan.

44. The aim of railway companies would appear to be the retention of as much traffic on the rails as is possible and to this end, they will doubtless attempt to so develop their highway auxiliaries in freight service that part at least of the journey will be made by rail. All developments of the past few years have tended in this direction; railhead deliveries and storage, the increased use of containers and demountable truck bodies, and the institution of highway services in rural districts not served by railway, are seen as the railway attempts at solution of the competitive traffic problem. Highway collection and delivery service has been extended as a vitally important feeder element.

45. The movement of the standard railway freight car over highways in terminal districts to deliver its contents at the consignee's door is obviously out of the question in this country although this very practice has been introduced in Germany where cars are much smaller and store door collection and delivery service is extended to carload shipments. Our railways can, however, further develop the container or demountable truck body, there seems to be little justification for both, thereby facilitating the transfer of merchandise to and from the railway car. Store door collection and delivery must be generally practiced and it must be an integral part of the railway function. No new service is involved. There is only the need for centralizing the responsibility for the complete service. To date, where store door service has been experimentally offered by the railways, augmenting their line haul service, store door collection and delivery has been optional. Under the ultimate plan, tariffs will anticipate the trucking expense involved at terminals, an important service of the privately owned truck will be eliminated, and the number of such trucks in operation, oftentimes in competition with the common carriers, will be reduced. There will thus be originated a standard truck, carrying a body which may be a railway container, and its flexibility will be correspondingly improved as will the flexibility of rail-highway transport. These trucks will be railway owned, or operated under con-

tract with the railways, and may be equipped with power jacks and winches to adjust truck platform height to car floor level and to permit the transfer of bodies to and from railway cars at any team track, or some other suitable arrangement will be devised to eliminate the necessity for providing more elaborate handling facilities. To encourage the use of such coördinated facilities, there is a present need for the standardization of a single size container, or perhaps a series of standard sizes and designs if such are found to be desirable in view of the diversity of shippers' requirements.

46. Where the distance involved is relatively short, less than 300 miles, the advantage now properly claimed in speedy transport by truck resides in the customary railway delay in setting the shipment in motion and in disposing of it at destination. While the small truckload unit may start from the shippers' loading platform immediately upon stowing the load upon the vehicle, the time allowed for delivery invariably extends to the opening of business activities on the following day. A properly scheduled train, supported by adequate highway service at the originating and receiving points, could produce identical service and at lower total transport cost. Unit handling methods are, however, essential in view of the very high platform costs involved in railway transfer. The magnitude of terminal costs is well developed in the reports of various railways, assembled in Interstate Commerce Commission Docket 21723. It is there shown that, of certain selected items of transport cost including terminal costs, road haul expense, car maintenance, and freight claims, terminal costs accounted for 70.79 per cent. of the total expense of the haul between New York and Buffalo while the road haul expense was but 23.55 per cent. of the total. Similarly, the Pennsylvania Railroad, reporting its l.c.l. operations between New York and Baltimore, showed a terminal expense 74.98 per cent. of the total and a road haul cost but 18 per cent of the total. Such facts are indicative of the present and possible costs of producing rail transportation and are suggestive of the means which should be employed. Where containers have been used to permit economies for the purpose of reducing the carload minimum and to compete with trucks, the introduction of containers has

been accompanied by marked rate reductions so that revenues from regular l.c.l. movements invariably appear in a favorable light when compared with the haulage of like tonnage in containers. Such comparisons are scarcely valid. Thus, in the study referred to above, the New York Central figures show a gross revenue of $13.76 per ton if moved in box cars or $8.71 per ton if containers are employed. The comparative revenue data reported by the Pennsylvania are $10.52 per ton in box cars and $5.15 per ton in containers. Such rate concessions offset the possible container economies and the tariffs upon which they are based impede the general exploitation of the possibilities of the service. At the present time the railway need for the use of containers or some parallel development is to accelerate movements—to permit the railways to acquire the speed of the motor truck in completing deliveries and to compete on the basis of convenience and speed within the trucking zone rather than in the matter of rates alone. The Federal Coördinator reports the results of his preliminary survey as indicative of the fact that over eighty per cent of the time that railway car equipment is engaged in a single movement, is absorbed in delays during loading, unloading, or awaiting dispatchment at intermediate points. Each transfer of lading of l.c.l. freight by the railways accounts for a 24 hour delay in delivery. There is a fertile field for improvement where such detentions are recorded. The need combines the use of both better adapted facilities and more modern practices, installed as a result of a careful study of the requirements of commerce.

47. The use of containers has also been shown to carry with it another important advantage. While it is sometimes pointed out that the empty movement of containers may add to the cost per empty car mile, the result of experiences on the Pennsylvania Railroad, covering the movement of 63,084 containers, showed that but seven per cent of the total number transported were hauled empty, a tribute to the adaptability of containers to all types of l.c.l. freight. Likewise, during a two week test period, the New York Central moved 791,718 pounds of merchandise freight in 64 box cars from New York to Rochester, N. Y. But 54,585 pounds in 6 cars moved in the opposite direction. During the same period, 622,851

pounds were carried in 27 container cars from New York to Rochester and the return movement comprised 1,069,925 pounds in 33 cars.

48. It is apparent that the validity of low freight rates by truck originates largely with what might be termed the inefficiency of rail transport in like service—features susceptible to improvement by the adoption of carefully studied measures in which the container, suitably proportioned and adequately serviced by trucks selected for adaptability in terminal operations, and with a chassis designed for quick and convenient transfer of containers, figures conspicuously.

49. Our real danger today lies in weakness of spirit and confusion of understanding regarding the basic transport problem and essential institutions upon which alone we can build for the future. This spiritual weakness and intellectual confusion have arisen in part from the stress of the changing times through which we have been rapidly passing, which has made many of us willing to sacrifice everything in the future for present necessity and expediency. But our attitude has roots that go deeper than the experience of the past few years and reach far outside the situation in our own sphere.

50. In national policies, the railways have shown a large degree of coherent effort. As regards competition and rivalry among adjacent lines there is still the need of bringing a higher quality of business intelligence to bear on present problems than now exists. It may be that the events which ushered in the new era of competitive transport crowded upon one another in such rapid succession that the railways were unable to judge the power quickly to develop with the phenomenal growth of these new forces. It is certain that it would have been unnecessary for them to surrender such volumes of traffic had they promptly reconstructed their policies to effectively utilize each new arrival on the transport stage as soon as it became a factor in the movement of persons and tonnage. Rather than to assume an aggressive attitude and expand their own operations, the railways fought their competitors, jealously guarding what they claimed as their rights—but with little success. The records show the futility of their efforts. Highway, pipeline and air transport grew

and have independently established themselves in the role of essential servants to the public and have been so received. They now claim rights of their own—certain competitive privileges which it will be difficult to compromise by the tardy efforts of the railways to absorb them into a coördinated transport system. Fortunately for the railways and public, transport occupies so important a place in the national interest that no transport organization less perfect than the best which it is possible to create can long endure, and the ideal plan can now be visualized without difficulty. The railways are suffering from seriously depressed income, arising from a cause independent of trade conditions. Few of their competitors are genuinely prosperous. Yet the total volume of the nation's traffic continues to grow even though the rate of increase shows a definite trend toward saturation. One need look no further than to the economic law of supply and demand for the cause. The railway investment of 26 billion dollars furnished all the facilities required to move the nation's goods and to furnish required communication. Motorized highway transport, in the span of its brief existence, has doubled this transport capitalization and to this must be added the money expended to create new inland water courses, pipelines, and air service, all adding to the depreciation, interest, and maintenance costs which the various agencies, as public servants, must derive from the people served.

51. In the final plan, the efficiency of service will, as has already been observed, dictate the volume of traffic enjoyed by each carrier included in the transport organization. Duplication and triplication of parallel facilities will be stopped and the regret will be that the extent of unwise investment was so great since it will impose at least a temporary burden and add to the difficulties to be encountered in bringing about a practical distribution of business. It is difficult to scrap or to restrict the use of existing facilities especially on the grounds that a virtual competitor is better equipped to take over the work. Yet this must be accomplished. There will always be services for which two or more methods of transport may be well adapted. Convenience is a difficult element to appraise in terms of money. All users of transport do not seek the same features. To the end that these overlapping

functions may be eliminated as far as possible, it is essential that each separate organization develop the possibilities of its own field to the limit and allow the public to define the extent to which the process of cost saving by elimination of duplicate services may be carried.

(To be continued)

Solution Cycles as Applied to Step-up Transformers for Temperatures

Dr. George Granger Brown, in a contribution bearing the above title, which appeared in the JOURNAL for April 1935, page 405, refers (on page 412) to a steam pressure transformer described by Prof. Lionel S. Marks in *Mechanical Engineering*, June 1927, Vol. 49, page 600.

The author's attention has recently been directed to the following which appeared in *Mechanical Engineering* for February 1928, Vol. 50, page 173:

A STEAM-PRESSURE TRANSFORMER.

To the Editor:

There is an error in the article entitled "A Steam-Pressure Transformer" which appeared in *Mechanical Engineering* for June 1927. The equation on the second line of the second column of page 601 should be $h_0 = h - \Delta h + L_0$, where Δh is the difference between the sensible heat of water at the temperature in B and the temperature of steam entering B. In the original article Δh is omitted.

With this correction columns 7–10 of Table 1 and column 8 of Table 2 are changed to the following values:

TABLE 1				TABLE 2
(7)	(8)	(9)	(10)	(8)
1.312	1.937	1.194	1.206	0.653
1.236	1.629	1.373	1.374	0.698
1.174	1.423	1.528	1.523	0.740
1.123	1.279	1.659	1.652	0.752
1.097	1.242	1.688	1.682	0.818
1.073	1.186	1.748	1.742	0.850

LIONEL S. MARKS.

THE NATURE OF THE COSMIC RADIATION.*

BY

THOMAS H. JOHNSON, Ph.D.,

Assistant Director of the Bartol Research Foundation of The Franklin Institute and Research Associate of the Carnegie Institution of Washington.

I. HUMAN VALUE OF COSMIC RAY INVESTIGATIONS.

BARTOL RESEARCH FOUNDATION
Communication No. 88.

Scientific research projects divide themselves into two classes according to the human value of the results; those from which some new device or method develops, augmenting our comforts, conveniences or abilities, and those resulting in new points of view. Values of the first type are evident in every phase of practical living. The second are not as generally appreciated, though the values are often more genuine.

It is not always possible at the outset to know into which class a particular search for the truth will fall. Oftentimes values of both types develop. But in the case of certain astronomical investigations, of which the study of cosmic radiation is typical, the philosophic interest is paramount. The total energy falling upon the earth's surface in the form of cosmic radiation is about one-thousandth of star light or one-billionth of sun light. Even if the cosmic ray energy were equal to sun light it would probably be an inferior source of power, for the extreme penetrating ability of the cosmic radiation prevents its concentration for conversion into useful forms of work.

II. METHODS OF INVESTIGATION.

Although the cosmic ray intensity is minute when expressed in terms of *total* energy, single cosmic rays possess more energy than any other known form of radiation, and they are easily detected, one at a time. If we had suitable nerve responses we would be conscious of about twenty-five cosmic ray shots through some part of the body each second. The rays may be detected in several ways, all of which depend

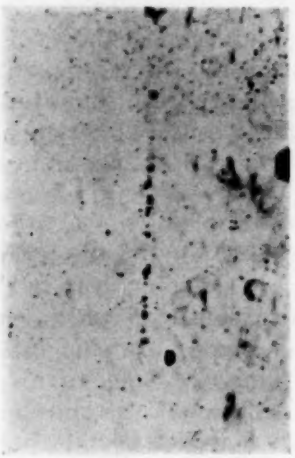
* Presented at the Stated Meeting held Wednesday, January 16, 1935.

upon the ability of a cosmic ray to ionize, or split apart, the electrical charges of the atoms of matter through which they pass.

If the air in a chamber is supersaturated with moisture the charged atomic fragments, or ions, act as centers of condensation for droplets of water and these may be photographed. Figure 1 shows such a photograph of the ion trail left in the wake of a cosmic ray.

Another simple device for detecting ionizing radiations is

FIG. 1.



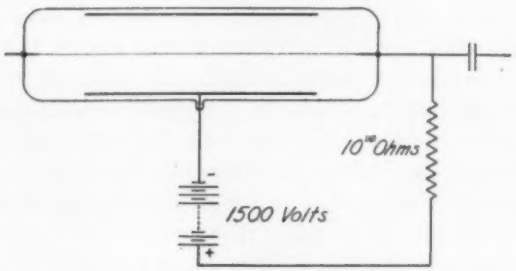
The cloud track of a cosmic ray, consisting of a row of water droplets condensed upon air molecules which have been ionized by the ray.

the Geiger-Mueller counter, represented in Fig. 2. A metallic cylinder is placed in a glass tube, within which the air pressure is reduced to about a tenth of the normal atmosphere, and a fine wire is stretched along its axis. In operation the cylinder is charged negatively to 1,500 volts and, if a ray produces as much as a single ion within the cylinder, this is swept by the electric field towards the wire. As it approaches, the acceleration increases until the energy gained between encounters with atoms of the air cause it to ionize these at each successive collision. Each new ion becomes an ionizing agent and an avalanche resembling an electric spark is started. The flow

of electric charge becomes great enough to be detected directly or it can be amplified and recorded on a suitable electric device.

When a small counter of this kind, 4 cms. long and 1 cm. in diameter, is connected to an amplifier and loud speaker, about twenty clicks are heard in a minute. A radioactive substance placed near the tube can increase the count to several hundred a minute, each count indicating the passage

FIG. 2.



Diagrammatic sketch of the Geiger-Mueller counter and its electrical connections.

of one ionising ray. The radioactive radiations are well known and will not come into the discussion further. The subject of interest pertains to the twenty rays per minute indicated when all radioactive materials are removed.

These rays have been known to exist for thirty-five or forty years but only in recent times have differences been recognized between them and the radioactive radiations.

One such difference of particular significance in the investigations is the ability of the residual radiation to excite avalanche discharges in several tubes at once. If two counters are connected in an appropriate electrical circuit the simultaneous discharges can be automatically selected from the others and recorded separately. In the case of two large counters whose individual discharge rates are about three hundred a minute, practically no simultaneous discharges occur when the tubes are separated, but if one counter tube is placed directly above the other such simultaneous discharges or "coincidences" are frequent. In the latter position

single rays can pass through both tubes. The advantage of this arrangement for the cosmic ray measurements is that the radioactive radiations have no effect. Such rays, if of the penetrating gamma type, excite discharges only when they convert themselves into the non-penetrating beta type within the counter cylinder. One gamma ray can never excite more than a single counter. The coincidence counters thus select the cosmic rays for their recording and, furthermore, they pick out only the rays which are coming from within a small range of directions.

A third method of investigation consists of measuring the current of ions produced directly by the cosmic rays in a vessel filled with gas. To increase the effect the vessel is usually filled to a high pressure and often the current measuring instrument is placed inside. Radioactive radiations can be eliminated, if necessary, by lead shields on the outside. These instruments, called electroscopes, have been used to a large extent in cosmic ray intensity surveys. Though extremely accurate and reliable they suffer a disadvantage in not being able to determine from what direction the rays are coming.

III. EVIDENCE THAT RAYS ARE OF COSMIC ORIGIN.

Experiments with all three types of instrument have built up convincing proof that the rays are of cosmic origin. By rotating the line of two coincidence counters, the intensity of cosmic rays can be studied as a function of the direction. This directional distribution favors the vertical and very little intensity is incident from the horizontal. Most of the cosmic rays are coming down from above at steep angles. This type of angular distribution would be expected if the rays originate outside the atmosphere, for they would be absorbed at the low angles in proportion to their longer paths in the air. A source outside the earth was proposed as early as 1913 by Hess who carried apparatus in a balloon and found the intensity increasing with elevation. At the height of 4,300 meters four times as many rays strike a square centimeter of surface per second as at sea level, and a three hundred fold increase over sea level intensity has been found in the stratosphere. All evidence points to the regions beyond the atmosphere as the source of the cosmic radiation.

IV. PROBLEMS FOR INVESTIGATION.

What are these rays which come to us from the depths of cosmic space? How, where, and under what conditions are they produced? What can they tell us of the conditions in other parts of the universe, both at their place of origin and in the interstellar spaces they traverse? What are the effects of their bombardment on our own planet? Many problems present themselves for investigation. The field is a new one to science, and like Aladdin, we wonder what new mysteries are about to be revealed. One must not be impatient for the revelation is slow and involves many difficulties. Some progress, however, has already been made, particularly in regard to the problem of the *nature* of the radiation.

To understand what cosmic rays are, involves knowledge of their electrical charges, their masses and their energies. These are the quantities which play the significant roles in determining the behaviour of a ray. Are the rays electrically neutral or are they charged? If charged, are they positive or negative, and how much charge do they carry? How much inertia do the rays possess and do their masses correspond with any known particles? How much matter would have to be converted into energy in their production, or through what differences of electric potential would the rays have to fall to gain their energies? The questions are not only interesting in themselves but their answers will be helpful clues in tracing down the places and processes of origination.

V. METHODS FOR ANALYSIS OF THE COSMIC RADIATION.

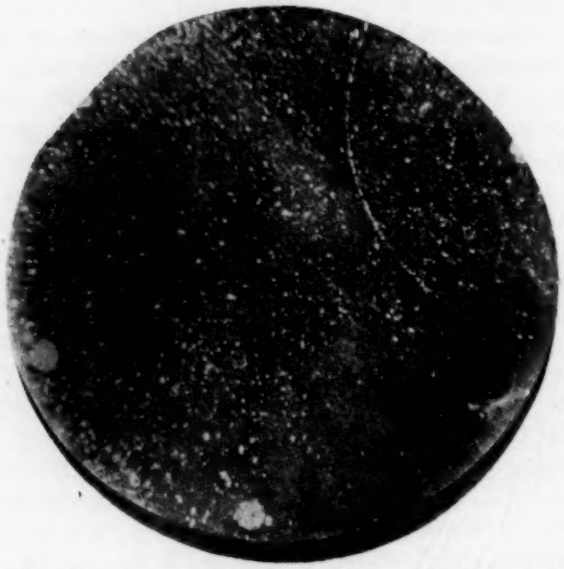
With the technique in hand for detecting cosmic rays and measuring their intensity, methods of analysis have developed. For many years after their discovery the cosmic rays were commonly supposed to be photons, similar in character to the X-rays, the gamma rays, or the light rays. Experience had shown that rays of this type were more penetrating than corpuscular rays of equal energy and it was natural to assume that the extremely penetrating cosmic rays were also photons. Even on this assumption it was necessary to postulate energies far in excess of anything known, to account for their great depths of penetration through matter.

A more discriminating method for the analysis of radiation

than that of the studies of penetrations consists in determining the deflection when the rays are passed through a magnetic field. If the ray carries an electric charge it constitutes an electric current and is subject to the same kind of force as is exerted on the wires of the armature of an electric motor. Under the action of this force charged rays may be bent into circular paths, the direction of curvature depending upon the sign of charge. Positive rays are curved oppositely to negative rays, and neutral rays pass through undeflected. Moreover, the radius of curvature determines the resistance of the ray to the magnetic bending force. This property, which we may call the *magnetic rigidity* or, for brevity, the *rigidity*, depends upon the product of mass and velocity of the ray divided by the amount of its charge.

In the case of the cosmic radiation a magnetic analysis has been carried out, using the method of cloud track photography, by Anderson in California, Kunze in Germany, and Blackett in England. A typical photograph of Anderson's is represented in Fig. 3. A magnetic field of 12,000 gauss was

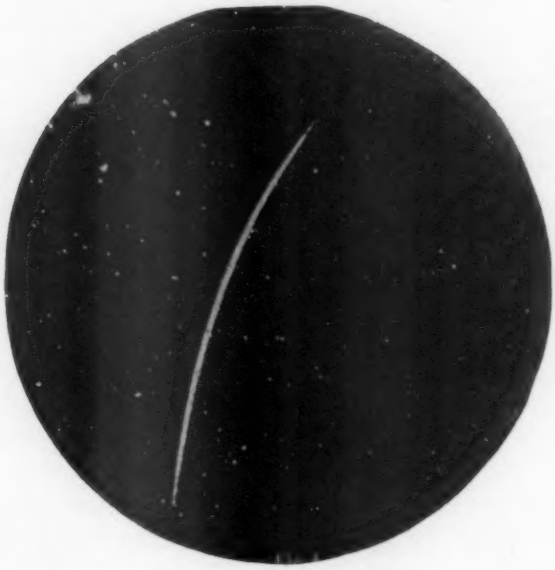
FIG. 3.



Cloud photograph by Anderson of an 18-million volt negative electron curved by a magnetic field of 12,000 gauss. The direction and amount of the curvature and the density of the track are data useful in determining what the ray is. (Physical Review.)

applied to the cloud chamber and the ray was bent into a circular arc. The direction of bending shows that the ray is negative. From the radius of curvature it is found that the rigidity of this ray *corresponds to* a particle of the mass and charge of the electron and with a velocity such as would be gained by a fall through a difference of potential of 18 million volts. The expression "*corresponds to*" is used because other values of mass, charge and velocity could give the same

FIG. 4.



Track of an alpha particle by Anderson illustrating the greater density of track resulting from the higher charge and mass as compared with that of the electron of Fig. 3. (Physical Review.)

rigidity. That the ray is really an electron may be inferred from the fact that the track is a thin one. A proton of greater mass but of the same rigidity would have been moving more slowly. With more time to act upon the atoms along its path the track would have been denser. If the charge were greater, as in the case of the alpha particle represented in Fig. 4, the track would have been very much denser. From all of the evidence it is possible to distinguish between the various kinds of rays, for the number of possibilities is

small. In fact the different kinds of rays believed to exist are limited to those with small integral values (0, 1, 2 etc.) of both mass and charge, the respective units being the mass and charge of the proton. All of the combinations known to exist are contained in table I. Those designated by (?) are

TABLE I.

Table of Elementary Particles.

Mass	0	1	2	3	4	
Charge						
−1	Negatron (negative electron)	Negative Proton?				
0	Photon Neutrino?	Neutron	Double Neutron?			
+1	Positron (positive electron)	Proton (^{1}H nucleus)	Deuteron (^{2}H nucleus)	Triplon (^{3}H nucleus)	—	
+2				Light alpha particle (^{3}He nucleus)	Alpha particle (^{4}He nucleus)	

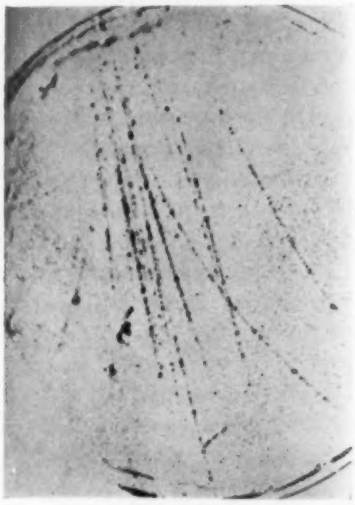
anticipated but not known to exist. The table extends along the diagonal to the lower right, including the nuclei of the stable atoms.

Because of the small number of entries in the table and because of the recognizable differences in the way rays of different charge and mass act upon matter, it is usually easy, except in the case of extremely high energy rays of equal charge, to identify the ray by its track. Practically all of the rays listed have been found associated with the cosmic radiation.

We know, however, that many of the rays found in the cloud chamber are secondaries produced from surrounding matter and there is difficulty in distinguishing these from the primary cosmic rays. Occasionally clusters of rays or

"showers," such as represented in Fig. 5, are found, apparently emanating from one or two points in surrounding material, as though they had been generated there by the impact of some very energetic primary ray. Even if the point of origin of a shower should chance to occur within the gas of the chamber and the ray generating it could be photographed, there would still be uncertainty whether it were not just another secondary from some previous shower. The presence of matter between us and the source of the radiation confuses the problem, and

FIG. 5.



A cosmic ray "shower" photographed by Blackett and Occhialini. The existence of secondary rays such as these invalidate the use of the cloud chamber as a means of analyzing the *primary* cosmic rays. (Proceedings of the Royal Society.)

if we are to know what the primary cosmic rays are we must have an apparatus which operates in the space beyond the atmosphere.

The proposal seems fantastic but actually the earth's magnetic field constitutes such an apparatus. The confusion of secondaries begins at the top of the atmosphere, only a few miles above the surface, but the bending force of the magnetic field begins to curve the primary rays at distances of thousands of miles. In determining the amount of such curvature, for calculation of rigidities, it is impossible to trace out the paths of single rays as was done in the cloud

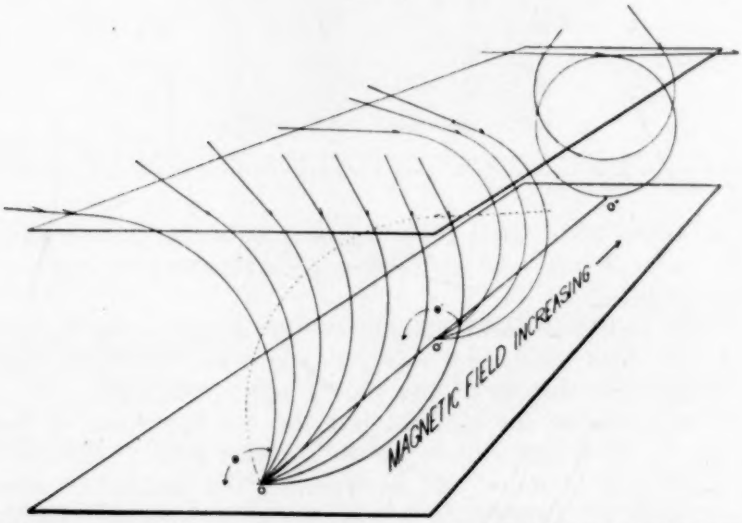
chamber analysis, for observations are limited to those which can be made on the earth's surface and within the atmosphere. But it will appear that this is no handicap, for the variations of intensity with changes of direction and position on the earth's surface give the equivalent information for the determination of the rigidity, and absorption in the atmosphere contributes the supplementary evidence, analogous to the track densities, for further identification of the type of ray. The two methods are equivalent, except that the earth-magnetic analysis concerns the primary rays alone.

VI. SIMPLIFIED ANALOGY OF THE EARTH-MAGNETIC ANALYSIS.

The relations between the rigidites of the primary rays and the measured intensities are complex and mathematical, but without going into the rigorous theory all of the essential points can be made clear by a simple analogy. The complexity of the real problem is due entirely to the peculiar form of the earth's field and if we consider an imaginary field of uniform extent and intensity the problem is simple indeed.

Referring to Fig. 6, we assume that an observer can make measurements of intensity from any direction and at any

FIG. 6.



Intuitive illustration of the essential elements in the earth magnetic analysis of the cosmic radiation.

point in the lower plane. This plane is analogous to the earth's surface and it prevents radiation coming up from below. Between the upper and lower planes a magnetic field has the direction of the arrow and is uniform over any section parallel to the front of the diagram, but is of increasing strength towards the back. The line $O\,O''$ is analogous to a magnetic meridian line in the northern hemisphere of the earth with the point O'' near the equator where the earth's horizontal field is strongest. Thus the right side of the diagram corresponds to the west.

The essential point in the analysis is the realization that the path of a ray in the region of the magnetic field is a circle, the radius of which depends upon the strength of the field and the rigidity of the ray. Rays are incident uniformly from all angles in the upper half of space but the observed distribution in the lower plane is altered. *Positive* rays of a particular rigidity, corresponding to the curvature of the paths represented, and incident from the left horizon reach the station O from some angle θ, or from the more inclined angle θ' at O' where the stronger field produces more curvature. At the point O'', where the field is still stronger, the same radiation may not be able to reach the observer at all. Referring again to station O, the angular region to the left of θ can be illuminated only by rays of higher rigidity than those which cut off at angle θ whereas these rays uniformly illuminate the region to the right. If no rays, other than those of the curvatures represented in the diagram, were present in the primary radiation, the observer would find a sharp cut-off in the intensity at θ. By measuring this cut-off angle, knowing the strength and extent of the field, the sign of charge and the rigidity can be determined. If rays are bent in the opposite direction, as indicated by the dotted orbit, the region of low intensity lies on the opposite side of the vertical. Thus, both the rigidity and the sign of charge are determined by the angle θ.

In case the radiation were not of a single rigidity, but had some kind of a distribution over all values, the sharp cut-off would be replaced by a gradually changing intensity. The difference between intensities at two angles would be due to rays whose rigidities lie within the range between the two

cut-off values. If positives and negatives were both present, the intensity difference at two angles would be equal to the excess in the number of charged rays of one sign over the other. Thus the angular measurements determine the distribution with respect to rigidity of the excess of one sign of charged ray over the other. To resolve the distribution of each sign separately angular intensity measurements must be combined with results obtained by varying the position along the meridian line $O\,O''$. In the case of a single value of the rigidity, the intensity from any direction such as θ' would remain uniform, as the observer moves along the meridian, until the position O' is reached where the intensity from this direction would fall suddenly to zero. In the case of a distribution this sudden drop would also be replaced by a gradually changing intensity and, in this case, the difference between intensities in any two positions is due to rays of both signs of charge, in proportion to their numbers, in the ranges of rigidity determined by the cut off angle θ' at the two positions. Thus, this type of measurement determines the distribution with respect to rigidity of the sum of the positive and negative rays together. Combining this result with the distribution of the excess of positives over negatives, we can discover the distribution of each component separately.

A change of intensity with position along the meridian can also be recorded by an apparatus which measures intensities from all directions, for example the electroscope, but the analysis of the distribution from this type of measurement is not as straightforward for the reason that the gradual change of intensity due to the changing angle of cut-off cannot be distinguished from the changing intensity which takes place at each angle due to the distribution of rigidities.

VII. THE PROBLEM OF THE REAL EARTH.

The only difference between the simplified problem and the problem of the real earth is in regard to the numerical relationship between any value of the rigidity and the angle at which it cuts-off, for any latitude. In the case of the real earth Størmer, and Lemaitre and Vallarta have determined these angles by solution of the mathematical equations of motion of the rays in the field of the magnetic doublet of the

earth. The results are illustrated in Fig. 7. The areas of the sky, represented in white, give the angles from which rays of the rigidity of a ten billion volt positive electron can reach the observer at the various latitudes. On the equator the bending force of the field is greatest and rays of this rigidity almost miss the earth completely. There is but a small white area on the western horizon. To reach the earth from all directions at the equator, rays must have the rigidity

FIG. 7.

Regions of the sky, represented in white, illuminated by rays of rigidity corresponding to 10 billion volt positive electrons.

of a sixty billion volt electron. In northern Mexico, on the other hand, the ten billion volt electrons can come in from all directions. Positive rays of low rigidity appear first on the western horizon, negatives on the eastern horizon.

VIII. THE EXPERIMENTAL MEASUREMENTS OF LATITUDE-INTENSITY VARIATIONS.

The first indication of an effect of the earth's magnetic field in altering the cosmic ray intensity distribution was found in 1928 by Clay. From his measurements the intensity seemed to be lower in equatorial latitudes. Compton's world survey, begun in 1932, has placed the result on a firm experimental basis and has shown that the intensity depends upon geomagnetic and not upon geographic latitude. The lower intensity at the equator is thus caused by the magnetic field

and not by some other systematically varying quantity such as temperature. Very careful studies of these variations by Millikan and his associates have resulted in accurate data, particularly in the case of automatically recorded sea level measurements. In all three cases electroscopes have been used and the results pertain to the average of the effects from all directions. Some directionally selective measurements, ideally more favorable for the analysis, have been made with coincidence counters mounted on ship board by Auger and Leprince-Ringuet.

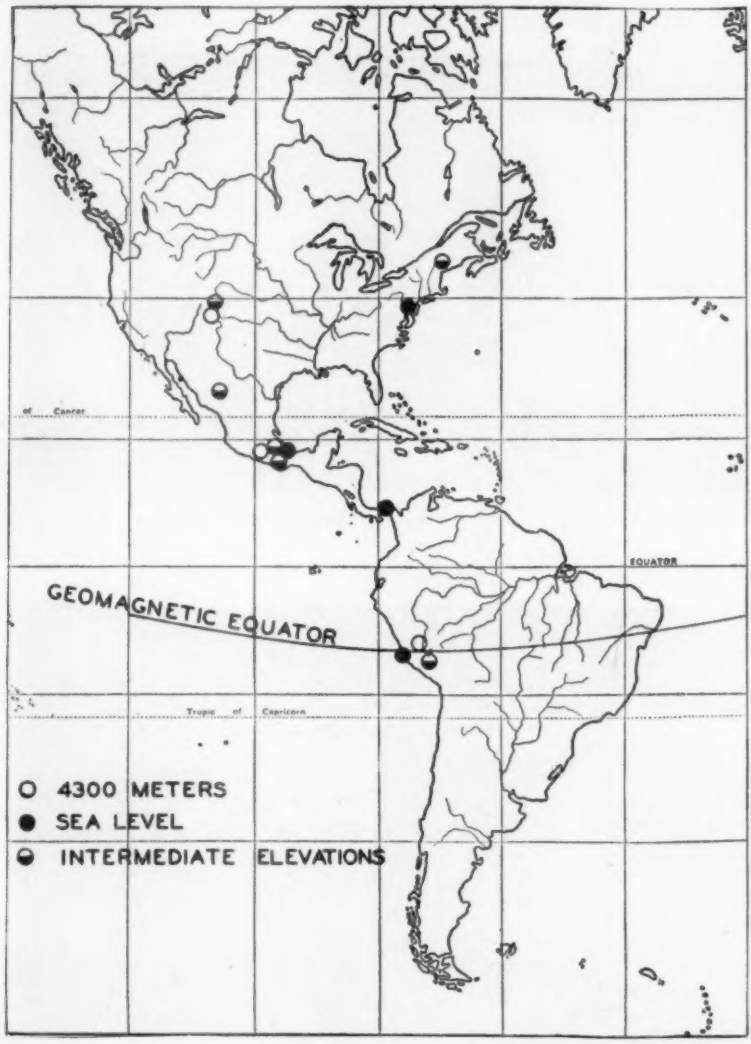
Compton's results are typical, and are particularly significant because of the wide range of latitudes, elevations and longitudes covered. Higher intensities occur at high latitudes and the increase with respect to the value at the equator is 14 per cent. at sea level, 22 per cent. at an elevation of 2,200 meters and 33 per cent. at 4,300 meters.

IX. THE SURVEY OF ANGULAR DISTRIBUTIONS.

Following the discovery by the writer and J. C. Street of an east-west asymmetry of the coincidences of aligned counters on Mt. Washington, N. H., in 1932, a survey for the study of this effect was planned with the coöperation of the Carnegie Institution of Washington and was begun early in 1933. Up to the present time the survey includes measurements at the stations indicated on the map of Fig. 8. Confirmatory results of significance have also been reported by numerous other observers.

The magnetic directional effect is manifest as an asymmetry, or a difference of intensities from eastern and western azimuths at the same zenith angle. The magnitude of the asymmetry is conveniently expressed as the ratio of the intensity difference to the average intensity for the two directions. In this form it is equal to the intensity of the unbalanced charged component in the range of rigidities determined by the cut-off values for the two angles, this intensity being expressed as the fraction due to this component of the total number of coincidence counts. Only the relative intensities are involved and the measurements do not have to rely upon the calibration of the sensitivity of the instrument. Changes of sensitivity during a measurement, however, must

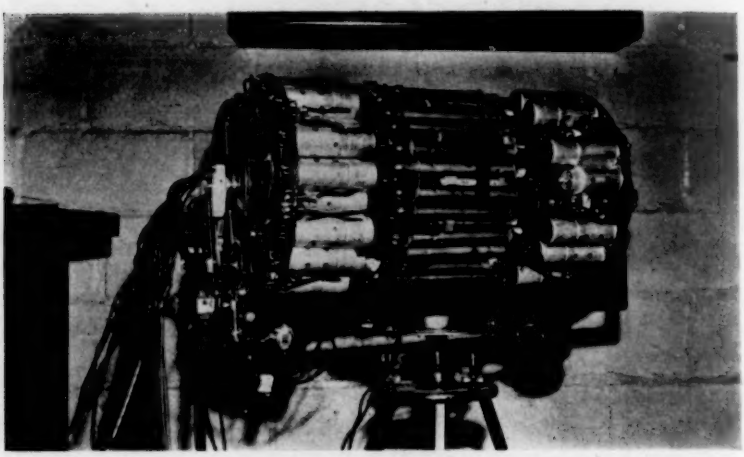
FIG. 8.



Stations where directional measurements have been made.

be avoided. Because of the rapid change of intensity with zenith angle, caused by atmospheric absorption, this angle must be kept accurately the same in both azimuths. With a

FIG. 9.



(*a*) Counters and amplifiers.

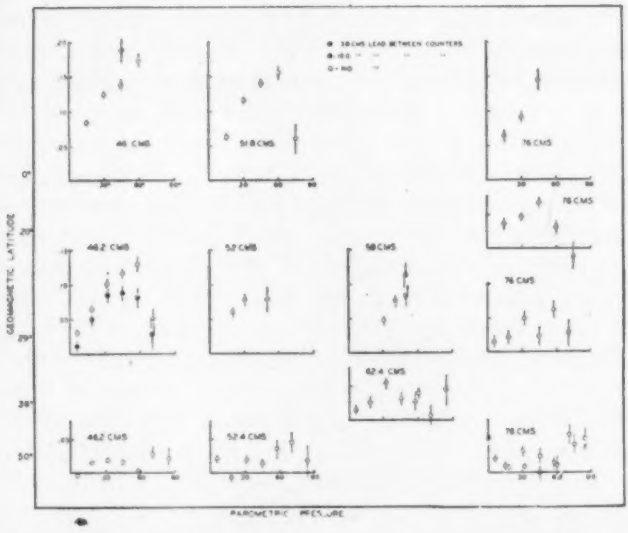
(*b*) Recording and timing apparatus.

Multidirectional cosmic ray meter for simultaneously comparing intensities in seven zenith angles and two azimuths. The operation is automatic with readings taken photographically on 16 mm. cinema film.

system of frequent rotations automatically controlled by clock works, about an accurately placed vertical axis, and with readings taken automatically, the problem of keeping a constant sensitivity under field conditions has been largely overcome and intensity ratios have been determined with an accuracy approaching the theoretical limit of the statistical fluctuations in the total number of rays counted. In many instances intensity differences of the order of ten per cent. have been measured with an error of less than one per cent. The apparatus which has been developed for this purpose, is represented in Fig. 9.

The results of the asymmetry survey are combined in Fig. 10. For each station the asymmetry, defined as above,

FIG. 10.



Combined results of the measurements of east-west asymmetries. Ratio of east-west intensity difference to average intensity plotted against zenith angle. Stations arranged in order of their latitudes and elevations.

is plotted against zenith angle. The ordinates are thus equal to the unbalanced charged component in the range of rigidities determined by the corresponding zenith angles. From right to left the stations are arranged in the order of increasing elevation and the rows are in the order of the geomagnetic

latitudes. In every case western intensities are greater, though the amount of the excess varies widely with zenith angles, latitude and elevation. Progressing towards the equator, there is a definite trend towards higher asymmetries and at each latitude asymmetries are greater at the higher elevations. At each station the asymmetry increases with zenith angle to a maximum value at 50° or 60° and thence falls off again towards the horizon. Though the accuracies and the range of stations are not all that are desired, the data present good indications of the general characteristics and the magnitudes of the effect.

X. ANALYSIS OF THE COSMIC RADIATION.

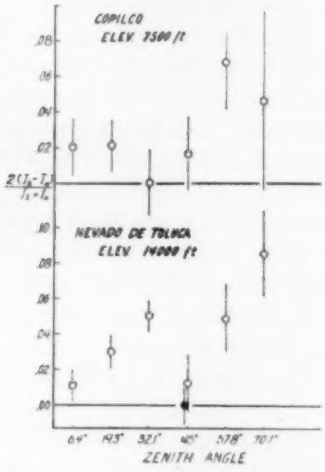
With the results of the directional measurements and those of the variations of total intensity with latitude, together with the calculations of the cut-off angles, we are in position to make a tentative analysis of the primary cosmic radiation. The method of attack and the results to be achieved are clearly before us but the course is not without its pitfalls.

Størmer's solution of the cut-off angles is simple in form and ready for application but it fails to distinguish between rays which are coming from infinite distances where sources of radiation exist and those which might have described closed orbits in the vicinity of the earth had there been sources of radiation near at hand. The latter orbits are vacant and must be left out of account. Lemaitre and Vallarta have studied these orbits and find that they would illuminate a range of angles just inside the cut-off limit as it is given by the simple Størmer theory. It is also shown that within this range of angles no infinite orbits reach the observer, and hence it is only necessary to make a correction to the cut-off angle in taking account of the vacant closed orbits. With this refinement of the theory, the angles illuminated by rays of a particular rigidity cover wider areas of the sky on the equatorial side of the east-west vertical plane, and a north-south asymmetry would be expected. Measurements in Mexico, represented in Fig. 11, show greater intensities from the south and confirm this detail of the calculation.

On the basis of Lemaitre and Vallarta's first estimates of

the true cut-off angles of infinite orbits, the experimental results led to the tentative conclusion that the primary radiation was practically all positive, and nearly uniformly distributed with respect to rigidity. Recent investigations by the same authors, in collaboration with Bouchaert have resulted in more accurate determinations of the true cut-off angles in the range of latitudes from the equator to 20°, but the theoretical work is not yet complete for higher latitudes.

FIG. 11.



North-south asymmetry of the cosmic ray intensity in Mexico, latitude 29° elevation 4,300 meters.

Without further consideration it is clear from the western excess of intensity that much of the charged component consists of positive rays unbalanced by negatives. Analysis of the asymmetry measurements in the equatorial zone shows that 14.2 per cent. of the intensity at 4,300 meters is due to positives unbalanced by negatives in the range of rigidities below that which cuts off in the east. At the same elevation in Panama 16.9 per cent. of the intensity is due to radiation below the same limit of rigidity and similarly defined. The higher value for Panama is due to the slight eastward shift of cut-off angles for each rigidity and the inclusion of lower rigidities from the west. The difference in these figures

(16.9% − 14.2% = 2.7%) is the change of the total intensity in this range of latitude which can be accounted for by unbalanced positive radiation. If the figure should agree with the measured change of intensity we could conclude that all of the latitude effect in this range can be accounted for by positives and that there is no negative component in this range of rigidity, contributing to the intensity at that elevation. Because of the absence of high mountains in Panama, accurate measurements of the latitude effect are lacking but the airplane measurements of Bowen, Millikan and Neher show that the change of intensity in this range is small and probably does not exceed 4 or 5 per cent. If the latter value is chosen as an upper limit the difference between 5 per cent. and the 2.7 per cent. accounted for by unbalanced positives, must be accounted for by a balanced component of positives and negatives in equal numbers. Thus the total negative component would have an upper limit of one-quarter of the total charged component. At sea level the excellent measurements of Millikan and Neher conspire toward a more conclusive analysis. At the equator the asymmetry shows that 10.4 per cent. of the sea level intensity is from unbalanced positives. In Panama the figure is 12.0 per cent. The difference 1.6 per cent. is the amount of latitude effect which can be accounted for by the unbalanced positives. This agrees with the average of Millikan and Neher's measurements of the total latitude effect and it is concluded that negatives in the corresponding range of rigidity make no appreciable contribution to the sea level intensity. This estimate is based upon the asymmetry measurements in Panama. If those at the equator had been used instead a larger latitude effect than that found would have been expected. Theory indicates no important differences between the asymmetries at the equator and in Panama, and the latter measurements appear to be the more reliable on the basis of the probable errors.

For the analysis of rays of lower rigidity the measurements in higher latitudes are ready and awaiting the completion of the accurate theoretical calculations of cut-off angles. Higher rigidities, on the other hand, can never be analyzed by this method as the earth's field is too weak.

Lower limits for the intensity in high latitudes of the entire

charged component, positives and negatives combined, can be given without further delay. For this purpose it is only necessary to add the unbalanced positive component at the equator to the measured values of the latitude effect. Expressed in terms of the total intensity at the equator, at least 16 per cent. of the sea level intensity and 30 per cent. of the intensity at 4,300 meters in latitudes above 50° is due to charged primaries. These figures represent lower limits from two points of view. In the first place the correction for possible negatives at the equator has not been taken into account, though it has been shown this is not necessary at sea level. The more important point is that much of the unanalyzed intensity at the equator may also be due to charged rays of higher rigidities. It might well be argued from similarities in the absorption that the unresolved equatorial radiation is of the same character as the radiation known to be charged, but this type of reasoning is obviously less reliable than that used in the above analysis.

Now comes the question of what these unbalanced positive rays are. Table I suggests three possibilities. The first is the positive electron, a particle of very nearly zero mass and unit positive charge. Rays of this type are often produced when high energy gamma rays collide with atomic nuclei and they are also generated in certain types of spontaneous nuclear disintegrations. Though considerably more rare than their negative counterpart, they could possibly be present in the cosmic radiation. The second possibility is the positive proton, the nucleus of the more common form of hydrogen. These occur in large numbers on stars and in the interstellar regions and are very likely candidates. This possibility would also include the mass two and the mass three hydrogen nuclei which occur in certain small proportions with the ordinary hydrogen. The third possibility is the alpha particle or helium nucleus which also occurs abundantly throughout the universe. Other heavier nuclei might also be included in this class. Their multiple charges and the consequent rapid loss of energy in traversing matter would seem to put these particles out of the picture as far as the sea level intensity is concerned, though they might well contribute to the intensity in the upper atmosphere. In fact alpha particles

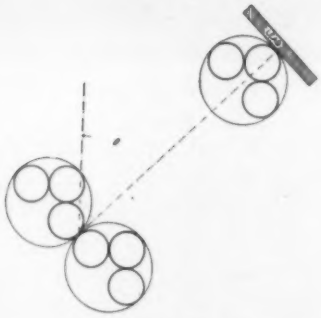
have been proposed by Compton as an explanation of some of the radiation observed in the stratosphere. At sea level and up to the tops of mountains, the principle candidates for the cosmic rays are thus the proton and the positive electron.

If the rays are protons, the component observed at the equator in the asymmetrical band at 30° from the vertical, lies in the range of energies from 11 to 20 billion volts. If the rays are positive electrons the energies extend from 12 to 21 billion volts. The range is outside the limits of previous experience and it is necessary to rely upon the predictions of untested theories for the final identification of these rays from their absorption characteristics. The test is difficult because the theories show on quite general grounds that rays of equal charges but different masses behave nearly alike if the energy is large compared with the energy equivalent of the masses. The mass of the proton is equivalent to one billion electron volts and the lighter electron is equivalent to a half million electron volts. Both are small compared with cosmic ray energies. Theoretically the two kinds of rays should be absorbed by matter nearly alike. For the process of the excitation of photon rays by collisions with nuclei, however, the difference in mass may be significant and there are reasons for expecting the electron with its smaller mass to excite photons more readily than the proton. To the extent that radiation losses are important ways for rays to lose energy, the protons should be the more penetrating.

At this stage in the analysis it would be extremely helpful to find a method of selecting one type of ray to the exclusion of the other, and if photon excitation is a unique characteristic of electron rays, an arrangement of apparatus, sensitive only to photons, would accomplish the desired end. Recent studies of the shower phenomena, illustrated in Fig. 5, seem to present such a possibility. Showers may be recorded to the exclusion of all other rays if use is made of their divergence in angle from the point of origin. Three counters arranged in a triangle and surmounted by a block of lead record coincidences only when a shower is produced in the lead. Several investigations have shown that the shower particles are generated in the lead by impact of a specific form of radiation, probably photons. If these photons are generated

by primary electrons, as the theory indicates, and not by protons, the showers can be used as a measure of the electrons to the exclusion of the protons. During the directional distribution survey showers were also studied in relation to changes of latitude, elevation and direction and the results are suggestive of electron primaries. It was found that the showers increase more rapidly with elevation than the total radiation though in this respect they cannot be definitely distinguished from the unbalanced positive component which gives rise to the asymmetry. In fact the results at first suggested that the showers were closely associated with the positive component. Measurements in Mexico of the dependence of shower intensities on azimuth have now shown that this is not the case. Using an arrangement of counters illustrated in Fig. 12, shower intensities from the east and

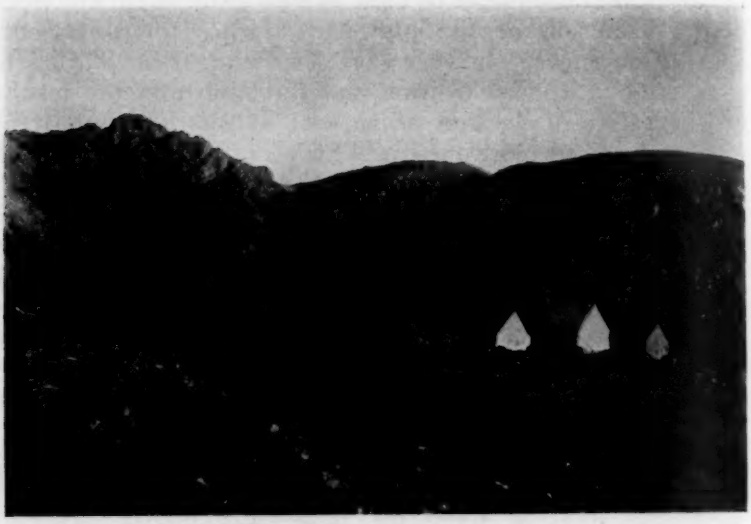
FIG. 12.



Arrangement of three counters and a lead block for detecting cosmic ray showers due to primary rays from particular directions.

west were compared and the results showed almost no asymmetry. Latitude intensity variations of this component on the other hand have proven that the showers are caused by electrically charged primaries. There is only one conclusion. The primaries which produce the showers consist of equal numbers of positive and negative rays. Until there is more evidence for the existence of the negative proton and in view of the ability of these rays to produce the shower generating photons we must regard this component of the primary radiation as an electron component. The equality

FIG. 13.



Cosmic ray station on the summit of Nevado de Toluca in Mexico, elevation 4,300 meters.

FIG. 14.

Cosmic ray station on the summit of Mt. Evans in Colorado, elevation 4,300 meters.

FIG. 15.

House used for cosmic ray measurements on Barro Colorado Island, Panama Canal Zone

in number of the positives and negatives is also agreeable to this view for the cloud chamber experiments of Anderson have shown that electrons often appear as paired positives and negatives. In spite of the evidence that much of the primary charged component is positive, there is still place to fit in a small balanced component of positives and negatives, particularly at high elevations. It may also be true that as far as the effects recorded by aligned counters is concerned the electron component is quite insignificant.

Having identified a component which is probably electronic and whose properties are different from those of the unbalanced positive component, the only remaining possibility for the latter is the proton, the nucleus of the hydrogen atom.

XI. THE SOURCE OF THE COSMIC RADIATION.

The existence of an intense unbalanced positive component suggests that we look for electric fields as the source of cosmic ray energies. Accustomed as we are to electrical displays

during thunderstorms and volcanic eruptions, it is easy to imagine similar processes taking place on stars. Negatively charged clouds of dust or condensed vapor, high above the surface of a star could draw out positively charged atomic ions from its surface or upper atmosphere and project them, like the beam of a cathode ray tube, into cosmic space. Nuclei of helium and hydrogen atoms, the principal constituents of the stellar atmosphere, would thus become the cosmic rays. During their passage through interstellar space these rays would encounter small quantities of matter and secondary rays would be generated. The secondaries could constitute the positive and negative electron component of what appears to us to be the primary radiation. If the picture is correct, one would also expect to find photons which would have been generated in a similar way in the interstellar spaces.

The secondary hypothesis of the origin of the balanced electron component raises the possibility of using its intensity as a measure of the total amount of matter in the space which the rays have traversed from their point of origin. Experience regarding generation of secondary cosmic rays requires the choice of ten grams per cm^2 as a lower limit for the amount of matter within which an observable electron component could be produced. This lower limit of matter can be translated into a lower limit of distance from the source for the change in color of distant stars gives a means of estimating the density of matter in interstellar space. Using Becker's estimate of 0.4×10^{-26} grams per cc., it results that distances of the order of from one to ten billion light years would have to be traversed before the requisite amount of material could be encountered. It is interesting that these figures are of the order of the diameter of the expanding universe as deduced from the red shift and are consistent with the idea that our principal sources of cosmic radiation are the extragalactic nebulae which are uniformly distributed throughout space.

Such speculations would lead to the conclusion that cosmic rays are of the same intensity throughout intergalactic space as here within our galaxy, and if this is the case, the total energy in the universe in this form exceeds that of star light. Thus any theory of the universe which leaves cosmic radiation out of consideration may fail to include an important element.

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Allantoin, Maggots and Wounds.—During the Great War or shortly after the credulity of most people was taxed by the announcement that bullet and bayonet wounds infested with maggots healed better and faster than wounds without them. Since then surgeons all over the world have used maggots in treating deep infections difficult to cure by ordinary surgery. Government entomologists, who have developed methods for rearing and shipping sterile maggots to hospitals, have at the same time sought the secret of this maggot's power to heal. DR. WILLIAM ROBINSON, of the Bureau of Entomology and Plant Quarantine, now finds that allantoin, which is given off by the maggots as they work their way through a wound, is responsible for part of this power.

Allantoin is not a new discovery, Dr. C. J. Macalister who used it successfully 23 years ago for ulcers, reported that European peasants had long applied the roots of comfrey, which contain allantoin, to sores. Recent test by Dr. Robinson show that allantoin is particularly useful for non-healing wounds, such as chronic ulcers and extensive burns that refuse to mend. After a few treatments, pinkish granulation tissue begins to grow and soon the tissues are knitting together rapidly. Healing from the bottom up can be ensured in a deep wound by applying the allantoin solution in a small packing at the base of the wound and covering the sides with vaseline.

Dr. Robinson made his discovery as the result of applied logic. He knew that no organism, except man, does anything with the sole purpose of helping another organism. He knew also that ground embryonic tissue taken from various animals has healing properties and that allantoin is present in such tissue. Therefore, he reasoned, maggots heal wounds through some involuntary act—perhaps excretion—and possibly such excretions contain allantoin.

C.

LIGHTNING CURRENTS AND THEIR VARIATIONS.

BY

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INTRODUCTION.

A knowledge of the lightning current and especially of its form of variation with time is of the most important value from a practical point of view. This is valid not only with regard to the most efficient construction of lightning protective devices, but especially for those used in high tension transmission lines. For the construction of effective lightning rods a thorough knowledge of the lightning current variations is also of the greatest importance.

On the other hand the problem of lightning currents includes questions of a specific physical interest.

Starting from this point of view it was deemed quite reasonable for the author to complete his earlier investigations of the electric field variations with corresponding measurements of the magnetic field variations.

With the aid of the magnetic field-variations under certain presumptions it was possible to calculate the current variations of lightning, both with regard to the form of variation with time and with regard to the absolute current values.

The author employed, in his earlier investigations of the electric field variations caused by lightning, specially constructed cathode ray oscillographs. The instrument was connected to horizontal aerials with known electric properties. The field variations from a lightning path could be easily recorded by employing such a system and it was thus possible to analyze the general discharge structure of lightning. Lightning was found to be constituted of a sequence of partial and similar discharges of varying intensity, and usually initiated by a characteristic pre-discharging procedure. We had also an opportunity of observing the general time-variation structure of the partial discharges.

Thus it seemed reasonable to try a similar method with regard to the magnetic field variations caused by lightning. With due consideration given to the velocity by which the partial discharges at lightning were developed it was, for this purpose, necessary to use cathode ray oscillographs with very high time sensitivity in connection to frame aerials with suitable electric properties.

The present paper is concerned with the methods and results of researches on the mentioned subject carried on at the Institute of High Tension Research, University of Uppsala, Sweden.

1. The Recording Devices of Magnetic Field Variations from Lightning.

a) The principles of measurements.

The observations of the magnetic field variations were carried out by using the induced effect from the fields on frame aerials. If the field force is H in cgs units and if the surface of the frame is A in cm^2 and its turn number n, the induced voltage (in volts) V follows from the well known relation (1)

$$V = nA \frac{dH}{dt} 10^{-8}. \tag{1}$$

The relation (1) is valid with the field lines passing parallel to the axis of the frame coil. With an angle φ between the lines and the axis the relation (2) will be as follows

$$V = nA \frac{dH}{dt} 10^{-8} \cos \varphi. \tag{2}$$

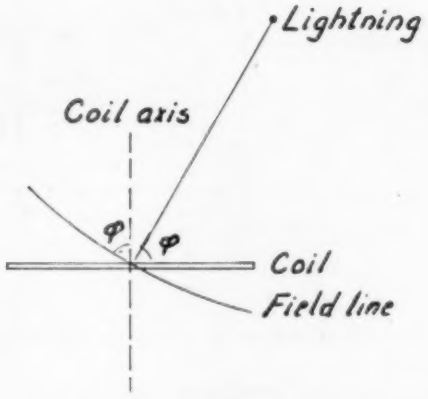
The observations referred to in this paper have been limited to lightnings, which have been vertically visible. In such cases we suppose the earth to be one of the electrodes, and a cloud charge the other in the charge procedure. We also suppose at such discharges to have the field lines in horizontal circles. The axis of the frame coil must in such cases be located in the horizontal plan. The principal arrangement is illustrated in Fig. 1.

The angle between the coil axis and the field lines = the angle between the plan of the frame coil and the direction

line to the lightning flash in question. The azimuthal location of the latter was determined by direct observation. For values of φ near 90° we receive very small values of V. Such a situation was avoided by using two systems of frame aerials exposed in two vertical plans at an angular difference of 90°. In such a case we usually receive two different voltage values V_1, V_2 from respective frame aerials. The usual direction finding relations are in such a case: $V_1 = \text{const.} \cos \varphi$: $V_2 = \text{const.} \sin \varphi$ or $tg\varphi = (V_2/V_1)$.

In a number of cases we observed simultaneously the values of the two coils which allowed a calculation of the

FIG. 1.



Coil orientation to lightning path.

corresponding values of φ. Simultaneously, the direction between the observation point and the lightning path was observed, by which procedure the value φ was gained. The difference between the directly observed angle value and the corresponding value of the frame observations was very small. The difference in the most unfavorable case was 12°. It followed from this that it was sufficient to use only one frame aerial when making our observations. Under such circumstances we had to use the frame that was most suitably located with regard to the direction between the observation point and the path of lightning.

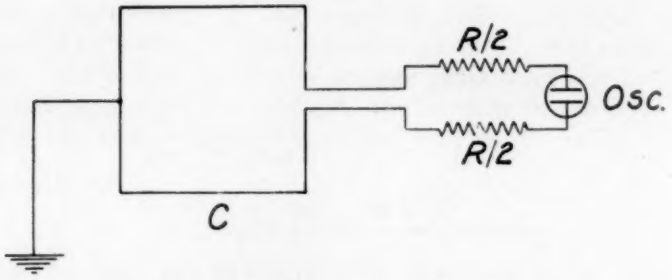
b) The coil system and connections to cathode ray oscillographs.

The two frames used when taking the measurements were exactly of the same dimensions, and they were constructed of rectangular flat coils with all the turns in the same vertical plan.

The turn surface nA of the frames was 1.95×10^7 turns cm.^{2} each. The wire of the coils consisted of copper with a diameter of 1 mm. In order to have as small a capacity as possible we fixed the distance between the lowest wire turn and earth to 70 centimeters. The half proper period of the coil constituted 2.8μ sec.

The external arrangements between the frame and the cathode ray oscillograph are illustrated in Fig. 2, where C is

FIG. 2.



Connection of frame aerial to cathode ray oscillograph.

the coil, R a damping resistance of 6000Ω against proper oscillations of the coil. The middle point of the coil was connected to earth. Both deviation plates of the cathode ray oscillograph were as illustrated by Fig. 2 symmetrically connected to the frame aerial. We could, by applying a full symmetry in the connection wires to the frame aerial, eliminate all disturbances from the electric field. Thus the recording device has only to react against variations of the magnetic field of the frame circuit.

2. The Calculation of the Lightning Currents.

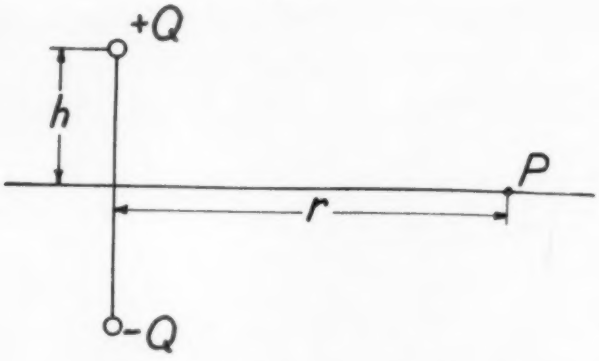
It was necessary, when using the field force for a certain observation point in the calculation of the current values of a vertical lightning to introduce certain assumptions especially

as regards the length of the lightning path and as regards the variation of the magnetic field with distance.

The really ideal solution in such a case would have been to record simultaneously at several observation points located at a suitable distance from the lightning path. Such an arrangement would have necessitated very extensive experimental equipment. At the present stage of our measurements we have found it satisfactory to introduce certain plausible assumptions as regards the observational data received from one observation locality.

We suppose the charge to be transported by a vertical lightning (see Fig. 3) to be $+Q$ at a distance of $2h$ from the

FIG. 3.



charge $-Q$. The distance to the point P where the magnetic field is observed is supposed to be r.

If a current passes between $+Q$ and $-Q$ with the relation $I = \frac{dQ}{dt}$, we receive from the equation of Maxwell the following relation (3) valid for the field force H_r:

$$H_r = \frac{2h}{r}\left\{\frac{1}{r}I + \frac{1}{C}\frac{\partial I}{\partial t}\right\}, \qquad (3)$$

where all relations are in e.m.u.

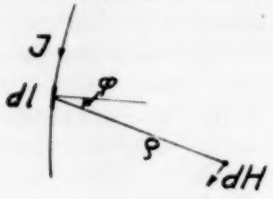
The relation (3) presumes the distance r to be great in comparison with h. This was not the case in our observations; we have a value of r of the same order as the value of h.

We can thus use the well-known differential relation (4)

$$dH = \frac{Idl}{\rho^2} \cos \varphi. \tag{4}$$

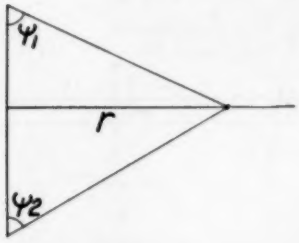
The indication of (4) is illustrated by Fig. 4. If we

FIG. 4.



integrate for a straight line (see Fig. 5) and if we express I in

FIG. 5.



ampères we have the relation (5)

$$H = \frac{I}{10r} \{\cos \psi_1 + \cos \psi_2\}. \tag{5}$$

This formula has been used in the following. We have assumed that the charge is radiated in all directions in the upper surface layers of the earth at the point of the lightning stroke. Consideration has also been given to the finite length of the lightning path, and we suppose the influence of this length to be expressed by the factor

$$f_h = \frac{h}{\sqrt{r^2 + h^2}},$$

which substitutes $\cos \psi_1$ in (5) with $\cos \psi_2 = 0$.

The relation (5) is thus transformed to (6):

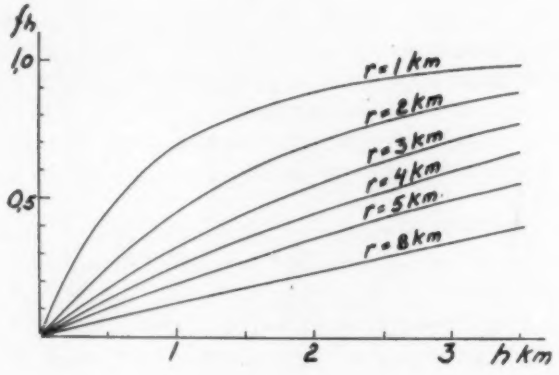
$$H = \frac{I}{10r} \frac{h}{\sqrt{r^2 + h^2}}. \tag{6}$$

If we substitute f_h in (6) we can calculate the current from the relation (7)

$$I = \frac{10rH}{f_h}. \tag{7}$$

In order to explain the importance of f_h and its variation with the distance we have in Fig. 6 plotted f_h against h for some different values of r.

FIG. 6.



In order to fulfil the calculation of I it will be necessary to introduce a probable length of the lightning path. We have for this purpose fixed this length to 2.5 km. We have deduced this value from some earlier measurements of the distance to the discharge centres by using simultaneous observations from 3 field stations. We had an opportunity of executing such observations during four lightning storms, and the most probable one was found to be 2.5 km.

The predominating distances between the lightning path and the observation locality varied in our following measurements from 2 to 4 km. In using these distances a divergence from the supposed height value of $\pm$ 0.5 km will cause a

difference of about ± 8 per cent. Such differences will be smoothed out in a more extensive number of observations.

The displacement currents may, under special presumptions, influence the determinations of the current values of the lightning path. From calculations within the distances where we have observed the lightnings (2–4 kilometers from the lightning path) it follows that the influence of the displacement currents can be neglected.

We have further supposed that the field lines will follow in concentric circles around the lightning path. Topographic conditions can, in this respect, provoke certain local disturbances. We are, however, of the opinion that no such disturbances have been of any influence in the case mentioned here.

As we have already pointed out a more definite determination of the current values of lightning would have been required for simultaneous observations from 2 or 3 stations. We found it necessary while waiting for the results from such laborious experimental arrangements to publish the values we obtained by using only one observation station; especially as we do not consider the probable errors to be greater than 15 per cent.

There is, as will be observed further on, a very pronounced dispersion between the obtained maximal current-force values within an individual lightning with its partial discharges. This dispersion is much more pronounced within a thunderstorm with a sequence of lightnings. We must, from this consideration, not exaggerate the importance of the exactness of individual maximal current-force values.

From our point of view the most preponderant problem was a determination of the variation forms with time of the lightnings.

3. The Observations and Their Calculation.

The two aerial frames have been located in two directions at right angle: NE.–SW.; SE.–NW. respectively.

During the thunderstorm seasons of 1933 and 1934 we were able to take 130 separate oscillograms of magnetic field variations. The main part of these oscillograms allowed a calculation of field variations.

The measurements involved, as has already been mentioned, a determination of the voltage variation above the ends of the frame coil. The employed cathode ray oscillographic record method has already been described in earlier investigations of lightning phenomena in this JOURNAL.[1]

The recorded oscillograms contained the induced voltage variations caused by the magnetic field variations as explained in relation (1). We introduce the following values: V voltage of the oscillograph in volts, t the time in sec., $H\varphi$ the magnetic field composant in the frame plan, nA the turn surface of the frame aerial or 1.95×10^7 turns·cm^2.

Thus we have

$$\frac{dH\varphi}{dt} = \frac{V}{nA} 10^8 \tag{8}$$

or

$$H\varphi = \frac{10^8}{nA} \int V dt; \tag{9}$$

or with numerical values in c.g.s.u.

$$H\varphi = 5.12 \int V dt. \tag{10}$$

With regard to the angle φ between the plan of the coil and the direction line to the flash of lightning we have $H = H\varphi/\cos \varphi$. We have thus from the values of H a possibility of calculating the current I by using the relation (7) and where the f_h values are taken from the curves in Fig. 6.

4. Oscillograms with Different Recording Velocities.

Some difficulties arose during the oscillographic recordings in finding a most suitable time axis. We stated earlier [2] that an ordinary lightning flash contained several consecutive partial discharges. A time analysis of such discharges afforded a recording velocity which made it possible to read the curves within one to two micro-seconds. The total discharge procedure in a lightning flash on the other hand lasted up to several thousand micro-seconds. Such a dis-

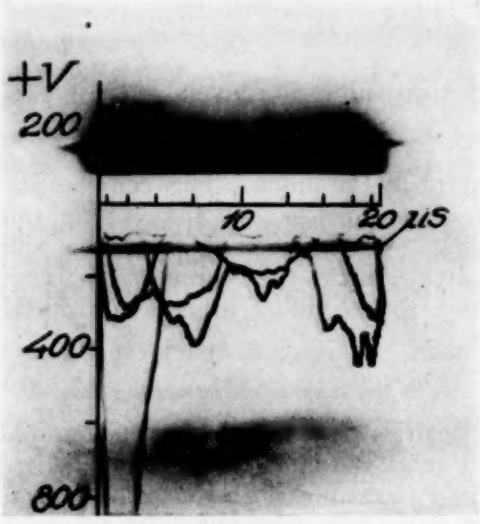
[1] H. Norinder, "On the Nature of Lightning Discharges," JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 218, No. 6, Dec. 1934.

[2] Loc. cit.

charge was sometimes built up of 5 to 7 individual and separated current pulses. With a high recording velocity it was in such cases very hard to separate the individual pulses especially with consideration being given to their time sequence. On the other hand when a slow moving recording time was used difficulties arose when analyzing the compressed time variations of individual partial discharges. The idea was to use two different recordings simultaneously with two cathode ray oscillographs recording on the same frame aerial.

Some oscillograms with a rapid recording time are reproduced in Figs. 7, 8, 9. Individual current pulses are easily

FIG. 7.

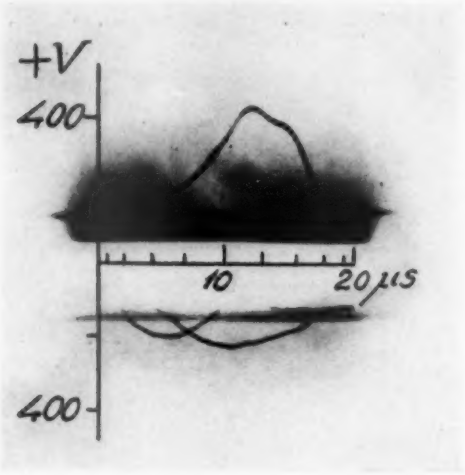


Oscillogram on frame aerials of lightning current pulses. Rapid recording time.

visible in these oscillograms but the recordings do not allow an interpretation of the time sequence of individual partial discharges.

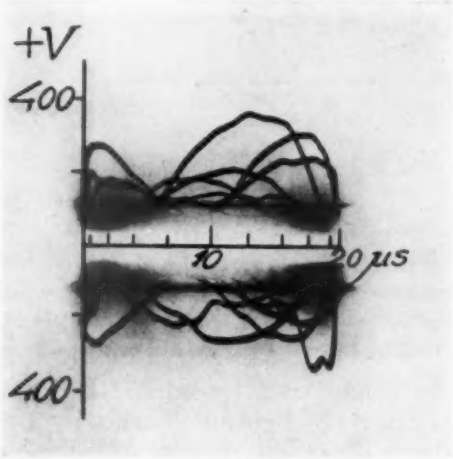
Oscillograms where a slow moving record method has been employed are reproduced in Figs. 10, 11.

FIG. 8.



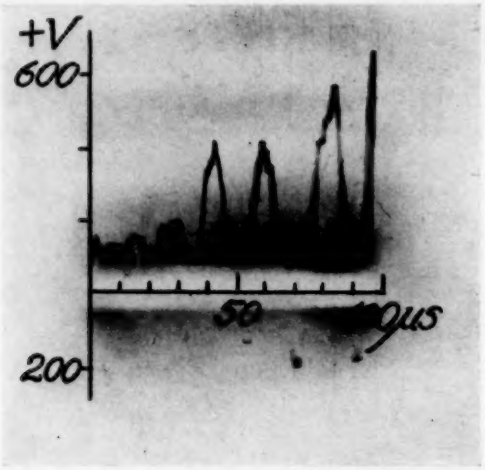
Oscillogram on frame aerials of lightning current pulses. Rapid recording time.

FIG. 9.



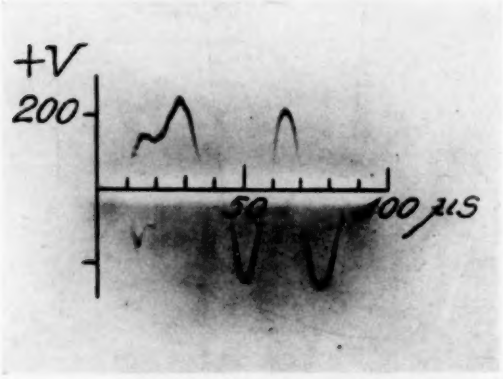
Oscillogram on frame aerials of lightning current pulses. Rapid recording time.

FIG. 10.



Oscillogram on frame aerials of lightning current pulses. Slow recording time.

FIG. 11.



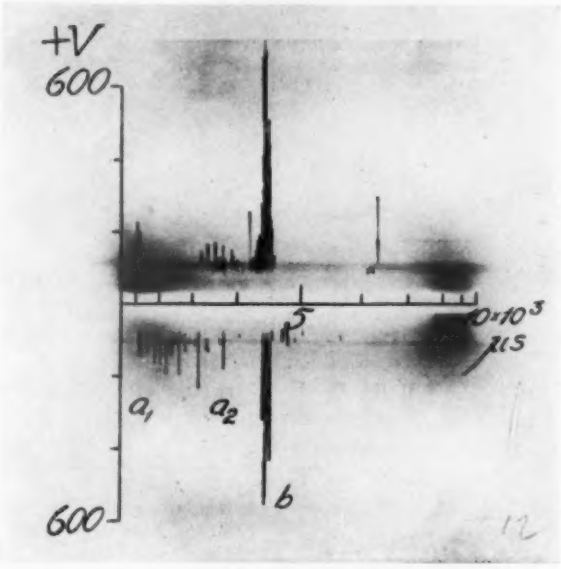
Oscillogram on frame aerials of lightning current pulses. Slow recording time.

5. The Time-Intervals of Sequent Lightning Current Pulses.

We have in some cases recorded the variations in the electric field as caused by lightning flashes by using horizontal aerials. We have simultaneously recorded the variations of the magnetic field by using the described aerial frames.

With regard to the proper partial discharges the agreement between the recordings was very good. Weaker pre-discharges, recorded by the horizontal aerials, were not visible in the oscillograms obtained by the frames. The reason for this was that, these pre-discharges were carried by very weak currents. We have, in order to illustrate this, in Fig. 12,

FIG. 12.

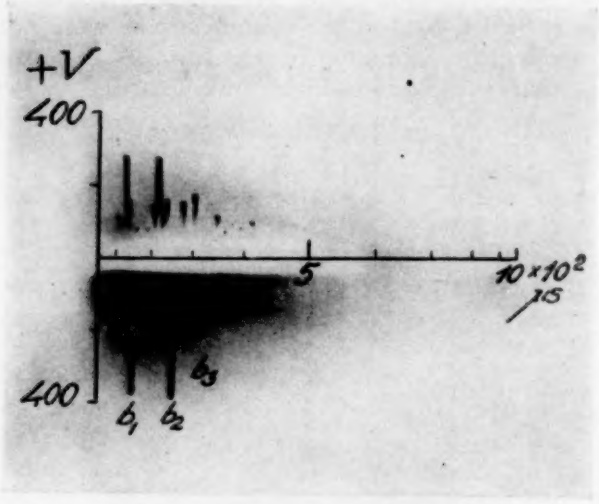


Oscillogram on horizontal aerial. Very slow moving record-time.

reproduced an ordinary oscillogram taken from the horizontal aerial and with a slow moving method. The oscillogram, which is very compressed as regards time, contains weak pre-discharges at $a_1 - a_2$, a group of partial discharges with high amplitudes at b. A simultaneous oscillogram from the frame aerial is reproduced in Fig. 13. The recorded time has not been so compressed in this oscillogram as in the case of Fig. 12. The partial discharges in Fig. 12 at b are visible as 3 discharge groups b_1, b_2, b_3 in the aerial frame oscillogram.

We have observed our oscillographic recordings with regard to the time intervals of sequent current pulses. The

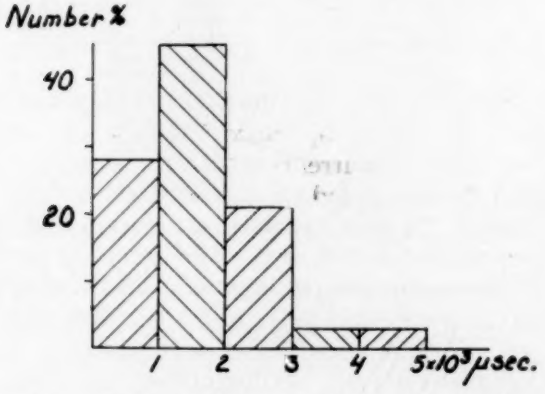
FIG. 13.



Corresponding oscillogram of Fig. 12 on frame aerial.

result of a percentage [illegible]ution in this respect is reproduced in Fig. 14. The [illegible] current time interval was from 1×10^3 to 2×10^3 mic[illegible]conds.

FIG. 14



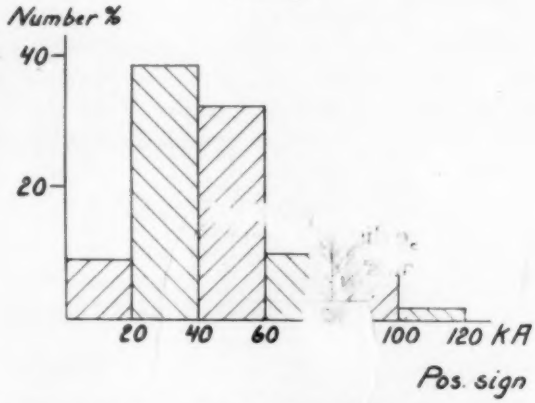
Percentage time differences between consecutive current pulses.

6. The Maximal Values of the Currents in Lightning.

We have with reference to what has already been pointed out calculated the current values of the oscillographed lightning discharges. Such a current force value was defined with regard to its polarity as positive when a positive charge was carried from the atmosphere to earth and as negative when a negative charge was carried to earth.

We have plotted the maximal current force values in kiloamperes as calculated from our oscillograms with reference to their absolute size. The percentage distribution of the values for positive and for negative discharges are reproduced in Figs. 15–16. A more pronounced difference between

FIG. 15.



Percentage distribution of crest values on individual current pulses.

the percentage distribution does not exist. The tendency is prevalent negative current values. This is more obvious when we calculate the average maximal current values. This value was for positive currents 47 kiloamperes, for negative currents 54 kiloamperes and thus prevalent negative currents of about 15 per cent.

The most occurrent maximal values varied from 20 to 40 kiloamperes but values of 40 to 60 kiloamperes were also usual. The extreme values of 100 to 120 kiloamperes did not, as could be expected, occur very often.

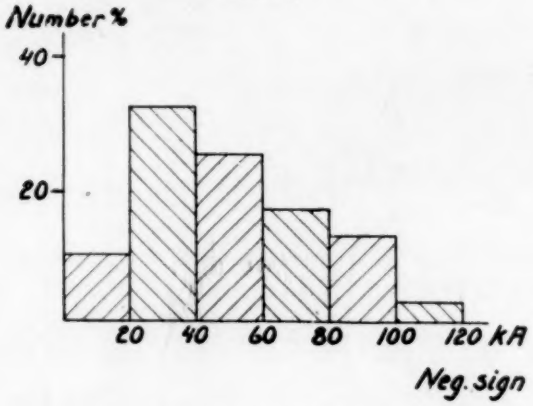
A lightning flash is, as has already been mentioned, built up of consecutive partial discharges. It is from this

point of view of interest to mention that the current signs of individual consecutive partial discharges did not always show the same sign. It did in some cases occur that a positive partial current was followed by two or three negative ones.

The lightning discharge was on the other hand sometimes initiated by a negative partial discharge followed by positive ones.

It was of special interest to compare our observations of maximal lightning current values with the current crest values obtained with the magnetic link method.

FIG. 16.



Percentage distribution of crest values on individual current pulses.

It has long been known how pieces of basalt are able to react as lightning stroke indicators [3] due to the remanent magnetic effects which are produced when the piece of basalt was hit by a lightning stroke. A method for measuring lightning current crest values based on similar magnetic properties has been developed by C. M. Foust [4] and G. F. Gardener.[5] The links consist of a number of thin strips of permanent-magnet steel with known magnetic characteristic. The magnetic links are located at a suitable distance from the con-

[3] F. Pockels Meteorolog. Zeitschr., Bd. 15, p. 141, 1898; Bd. 18, p. 40, 1901.
[4] C. M. Foust, *Gen. Electric Review*, Vol. 34, No. 4, April 1931.
[5] C. M. Foust and G. F. Gardener, *Gen. Electric Rev.*, Vol. 37, No. 7, July 1934.

ductor which carries the lightning surge current. The magnetic links can be magnetized by impulses of such short time variations which constitute the lightning currents. A condition for true values is a current flow in one direction, a property which limits the usefulness of the method.

Extensive observations by using magnetic links have been carried out in the United States by the General Electric Company, see W. W. Lewis and C. M. Foust [6] and in Germany by Studiengesellschaft für Höchstspannungsanlagen see R. Grünewald.[7] The observations in Germany have to some extent been carried out on lightning rods for buildings. The observed maximal currents thus obtained are in general accordance with our own values, and particularly so as still existing differences can be fully explained by dissimilarity in the measuring methods. The maximal current crest values obtained by the observations in Germany were 60 kiloamperes. The corresponding values from the United States reached 100 kiloamperes.

7. The Character of Time Variation in Lightning Currents.

The feature of the time variation in the lightning currents is of importance especially with regard to calculations and measurements of the discharge effects on transmission lines or lightning rod conductors.

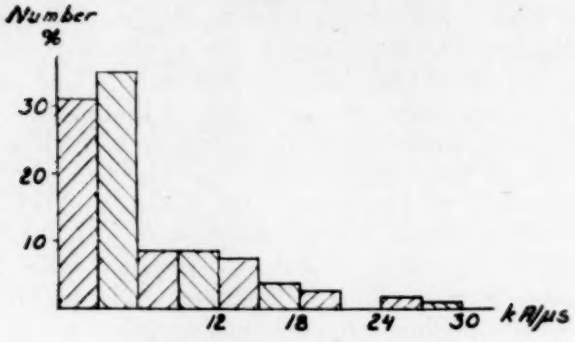
It was, from our observational data, possible to calculate the maximal changes with time in these lightning currents and the result is graphically reproduced in Fig. 17. The most usual change values with time was 1–3 kiloamperes/micro-second or 4–6 kiloamperes/micro-second. The extreme values of 20–30 kiloamperes/micro-second did not, as would be supposed, occur very often.

The total duration time t_1 of partial current pulses and the time intervals t_2 for the current variation in the dI/dt curves to reach its crest value have been calculated. The values of t_1 are reproduced in Fig. 18, from which follows a

[6] W. W. Lewis and C. M. Foust, "Lightning on Transmission Lines," IV, *Electrical Engineering*, August 1934.

[7] H. Grünewald, "Die Messung von Blitzstromstärken an Blitzableitern und Freileitungsmasten," *Elektrotechn. Zeitschrift*, 55, 21, page 505, 1934.

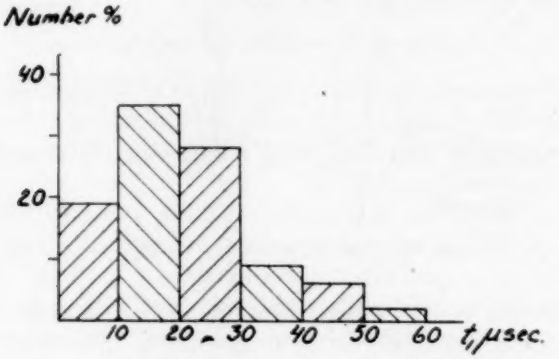
FIG. 17.



Maximal changes with time in lightning currents.

usual average duration of the current pulses to reach values between 10–30 micro-seconds.

FIG. 18.

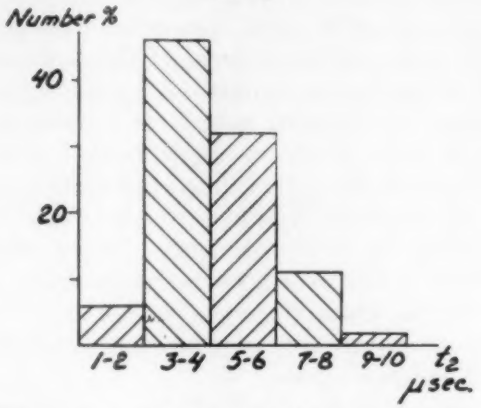


Percentage distribution of duration in time of individual current pulses.

The intervals giving the time of the current variation in reaching its crest value are reproduced in Fig. 19. The most common values vary between 2–4 or 4–6 micro-seconds respectively.

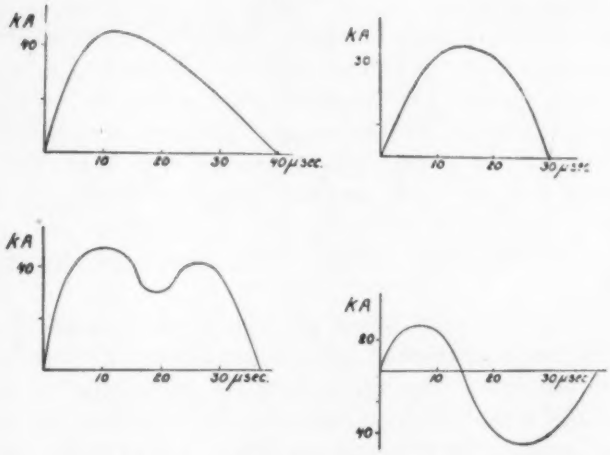
Some examples of the most typical time variation forms of lightning currents are reproduced in Fig. 20, where the unipolar types must be considered as existing either with positive or with a negative current direction.

FIG. 19.



Percentage distribution of time intervals for lightning current crest variation values.

FIG. 20.



Typical time variation forms of lightning currents.

8. Lightning Surges on Transmission Lines as Caused by Direct Strokes.

There exist, as we know, two different kinds of surges due to lightning on high tension transmission lines. The most severe type is caused by lightning strokes directly to the line. The other type, the induced surge, is provoked by electro-static induction when a bound charge is deliberated by

lightning, which is not striking the line. The voltage of an induced surge depends upon the initial electro-static field gradient, the time variation form of the discharge and the distribution of the bound charge.

To measure the induced surges on a transmission line is comparatively easy from an experimental point of view. It necessitates cathode ray oscillographs suitably located and connected by potential dividers to the line. Such surges occur, according to our experience, rather often when a lightning storm passes over a transmission line. The voltage amplitudes of the induced surges do not reach values high enough to cause any trouble as regards an exact measurement of their crest voltage values.

The surges caused by direct strokes to a transmission line are, on the other hand, much more difficult to observe and necessitate as well, for their measurement, the use of cathode ray oscillographs.

It is obviously pure chance if lightning happens to strike a transmission line at a place suitably situated as regards the observation point. It happens that when the locality of the stroke is quite in the vicinity of the oscillograph, the potential divider is not able to record the high voltage of the surge exactly. In another case the insulation of the line may be broken down by the surge before the voltage has reached its crest value. This obviously disturbs the recordings.

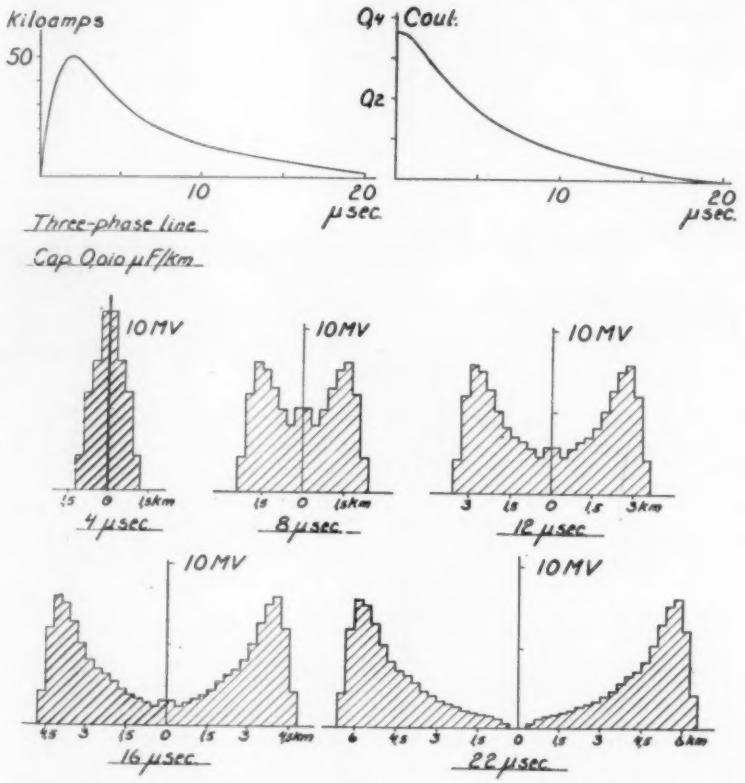
It is, on the other hand, possible to determine by calculation the surge provoked by a direct stroke of lightning to a transmission line. A condition for the calculation is a knowledge of the time variation form of the lightning current and the constants of the transmission line. For certain functional forms of the time variation a strictly mathematical calculation should be possible. A graphical method will again in the most cases give quite satisfactory values.

We have carried out such a graphical calculation of the surges, due to a direct lightning stroke to a transmission line. The capacity of the line was in such a case fixed at 0.01 $\mu F/km$. The insulation of the line was supposed to be high enough to withstand the crest voltage of the surge. The calculation was

performed for three different variation forms of lightning current as observed by us and considered as being typical.

The result of the calculation is illustrated in Figs. 21, 22, 23. The front slopings and the crest voltages of Figs. 21–23

FIG. 21.



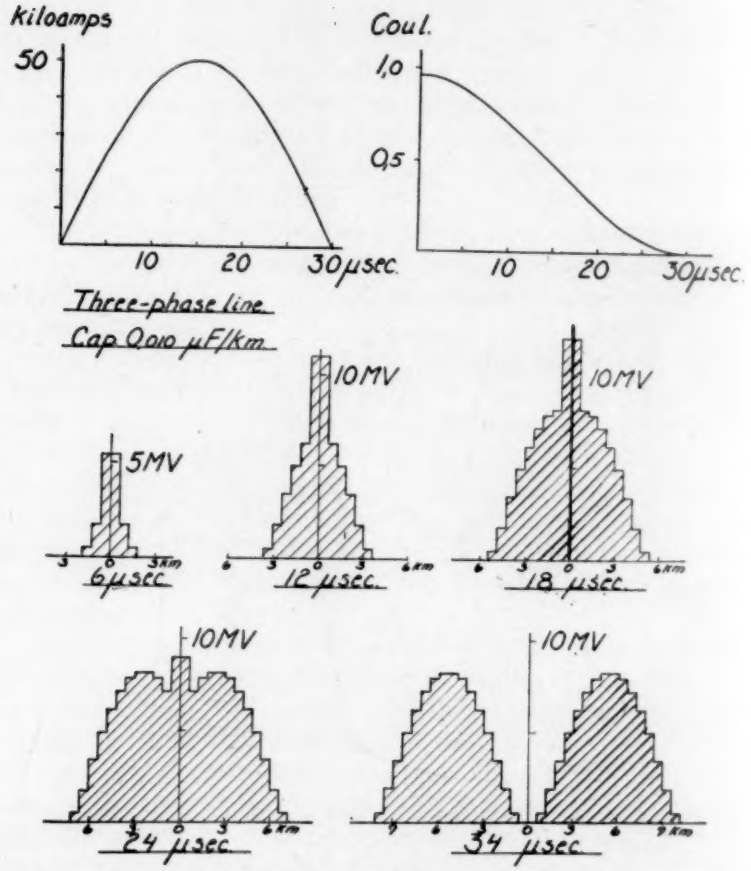
Lightning surges on transmission lines calculated from known current variation forms.

result in values which are in agreement with the few existing cathode ray oscillographic records of surges due to direct strokes.

An ideal condition for an undisturbed development of the calculated surges on the line is a perfectly high insulation, which prevents a flashover due to the surge. Another con-

dition is the possibility of neglecting the influence of corona effects on the voltage values. These two conditions are obviously not fulfilled in actual cases where the surge, at an early stage of its development, causes flashovers to other

FIG. 22.

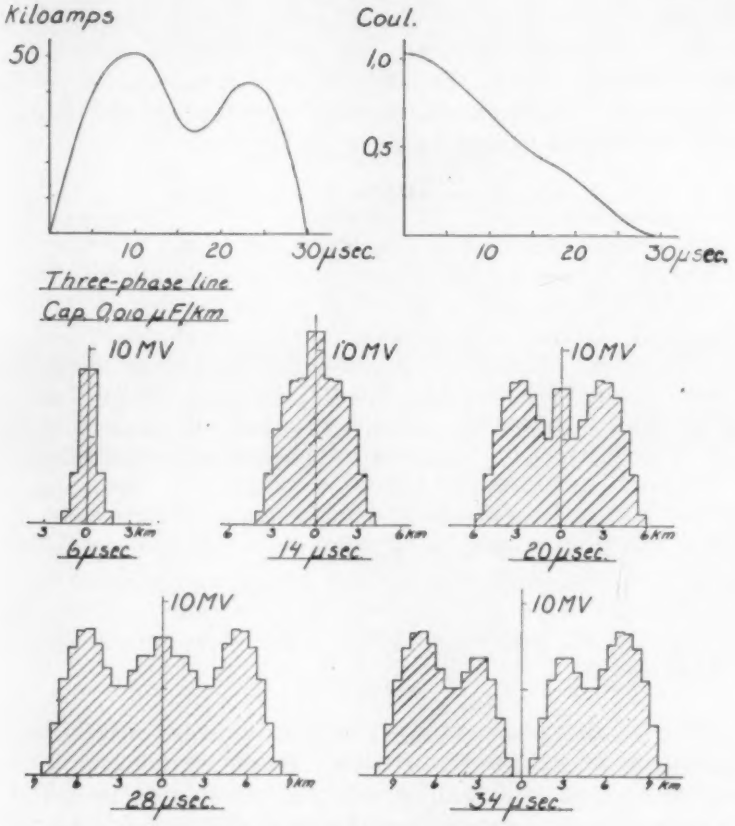


Lightning surges on transmission lines calculated from known current variation forms.

wires of the line than the one struck. Furthermore, it is only in exceptional cases that the insulators are able to withstand such high voltages as exemplified by the calculated surges without flashovers to earth. This possibility exists

when the poles of the transmission line consist of very dry wood.

FIG. 23.



Lightning surges on transmission lines calculated from known current variation forms.

9. The Total Charge Transported in a Lightning.

The total charge in a lightning current was earlier estimated to be of the order of 25 to 50 coulombs. From such values rather extensive volumes of a thunderstorm cloud were calculated to be dissipated by a few number of lightnings. This feature of the transport of charges in lightning was not supported by experience and particularly as systematic observations of the changes of the electro-static field from

thunderstorm clouds indicated relatively small volumes discharged by a lightning.

It was with regard to this interesting fact that we analyzed our own measurements of the lightning currents with respect to the transported charges. An integration of the current time variation curves obviously allowed a calculation of the corresponding coulomb values and the percentage distribution of the calculated values, as given in Table 1.

TABLE 1.

Coulombs.	Positive.	Negative.
0–0.50	18%	26%
0.51–1.00	11%	11%
1.01–1.50	7%	4%
1.51–2.00	7%	15%

The values are considerably smaller than those estimated earlier in an indirect way. No values were observed to be higher than 2 coulombs. Our coulomb values were a necessary consequence of the short durations of the discharges which were measured in partial discharges of lightning by our methods. In order to obtain from our observations the values up to 20 coulombs or more we either had to assume currents of the order of a million amperes or a duration of the discharge of the order of 1000 micro-seconds. Both these alternatives are impossible and contradictory to our experimental results.

SUMMARY.

In this paper an account is given of recent investigations of the nature of lightning currents. Frame aerials connected to cathode ray oscillographs made it possible to record the variations in the magnetic field caused by lightning discharges. A total of 130 oscillographic records was taken, which allowed a calculation of the current variation forms of the partial lightning discharges.

The most usual maximal current values varied between 20 to 40 kiloamperes. Values between 40 to 60 kiloamperes were also common. The average duration of the current pulses had values between 10 to 30 micro-seconds.

The transported charge in a partial lightning was calculated to reach not more than 2 coulombs, which low value had its reason from the measured short duration times of the partial lightning current pulses.

A SHORT ACCOUNT OF THE THEORY OF LUBRICATION.[1] II. FILM THICKNESS, FILM PRESSURE AND LOAD CAPACITY.

BY

MAYO DYER HERSEY,

Research Associate in Engineering, Brown University.

When the film is not of a uniform thickness there will be a positive fluid pressure developed in the converging portion of the film, as pointed out by Reynolds. This pressure supports the load, floats the journal or other moving surface, and under favorable conditions will entirely prevent metallic contact. A clear physical picture of the elementary mechanical actions taking place in the film is essential to an understanding of the complicated mathematical and experimental results now available.

RESUMÉ OF FRICTION RELATIONS.

We have seen that the coefficient of friction of a full journal bearing would be accurately expressed by Petroff's law,

$$f = 2\pi^2 \left(\frac{D}{C}\right) \frac{\mu N}{P}, \qquad (1)$$

provided the film thickness might be considered uniform. The coefficient is defined by F/W, where F is the equivalent tangential force of friction, and W the total load; F in turn being defined as the ratio of friction torque to the radius. In Eq. (1) μ denotes the viscosity, N the number of revolutions per unit time, and P the load per unit of projected area, W/LD. The length and diameter of the bearing are denoted by L and D, while C is the clearance, or difference between bearing and journal diameters.

When the film thickness is not uniform the frictional resistance may be calculated either from Lamb's formula for

[1] Section I of this paper (Introduction; Viscosity and Friction) appeared in the June issue, page 677. Sections III and IV are to cover the dimensional theory of lubrication, and the temperature relations in bearings, respectively.

power dissipated, Eq. (24) of Section I; or from Reynolds' formula for the shearing stress on the moving surface, Eq. (26) of Section I, which may be written

$$S' = \frac{\mu U}{h} + \frac{h}{2}\left(\frac{dp}{dx}\right). \tag{2}$$

The shearing stress, S', is the tangential force per unit area, the prime having been added temporarily to distinguish the shearing stress at the moving surface from the corresponding stress at other points in the fluid. Multiplying S' by an element of area, and by the radius to the point in question, and integrating gives the friction torque in the general case of a thrust or journal bearing. In the particular case of a cylindrical bearing the equivalent friction, F, may be computed directly by integrating the right hand side of (2) over the area of the moving surface. In this equation U denotes the linear velocity of the surface while h is the film thickness at any point identified by the coordinate x, and dp/dx is the pressure gradient in the direction of motion, p being the hydrostatic pressure at x.

The derivation of Eq. (2) follows very simply from Newton's law, in the form

$$S = \mu\left(\frac{du}{dy}\right), \tag{3}$$

and offers a convenient application for obtaining some familiarity with the mathematical notation of the hydrodynamic theory. In Eq. (3) u denotes the velocity of the fluid in the x-direction at any height y above the stationary surface. The basic assumption that the lubricant adheres to both surfaces is expressed by the boundary conditions $u = 0$ when $y = 0$ and $u = U$ when $y = h$.

The forces acting on the shaded element of fluid in the x-direction, Fig. 1 (a), are: (1) due to the shearing stress S on the lower surface, a force toward the right equal to $Sdzdx$; (2) due to the shearing stress $S + dS$ on the upper surface, a force toward the left given by $(S + dS)dzdx$; (3) due to the pressure p at the right hand end, a force toward the left equal to $pdzdy$; and (4) due to the pressure $p + dp$ at the left, a force toward the right given by $(p + dp)dzdy$. For equi-

librium, therefore, $dpdy$ must be equal to $dSdx$, or

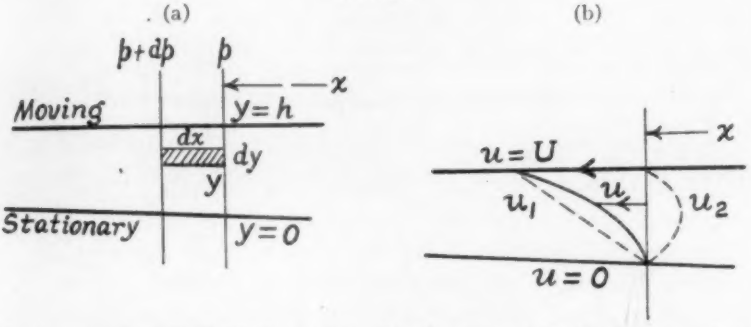
$$\frac{dS}{dy} = \frac{dp}{dx}. \tag{4}$$

Integrating with respect to y,

$$S = S_0 + y\left(\frac{dp}{dx}\right), \tag{5}$$

where S_0 is the stress on the stationary surface. Equating the right hand members of (3) and (5), integrating from $y = 0$

FIG. 1.



Film pressure and velocity distribution. (*a*) Location of an element $dxdyd_z$ (length d_z perpendicular to diagram). (*b*) Velocity distribution over a cross section of the film at x.

(where $u = 0$) to $y = h$ (where $u = U$) and solving for S_0 gives a value for this constant which converts Eq. (5) into the more definite form

$$S = \frac{\mu U}{h} + \left(y - \frac{h}{2}\right)\frac{dp}{dx}. \tag{6}$$

This reduces to (2) upon substituting the particular values $y = h$ and $S = S'$.

It is interesting that the tangential stress on the moving surface, S', and the corresponding stress on the stationary surface, S_0, are in general unequal. The difference $S' - S_0$ is given by the expression $h(dp/dx)$. The reason will be evident from Fig. 1 (b), where the velocity distribution curve for u as a function of y has been analyzed into the two component curves u_1 and u_2. The curve u_1 shows the linear velocity

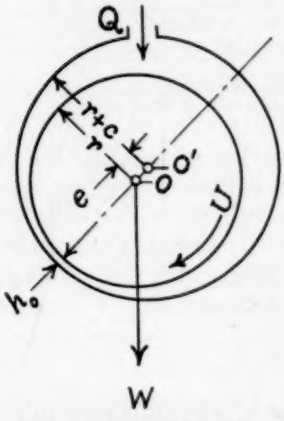
distribution due to the relative motion of the two bearing surfaces in the absence of a pressure gradient. The curve u_2 shows the parabolic distribution which would result from the pressure gradient alone, if the bearing surfaces were fixed in position like the walls of a capillary tube. From Newton's law, the shearing stress at any level from $y = 0$ up to $y = h$ is proportional to the slope of the curve, du/dy. At the moving surface this slope is equal to U/h plus a term depending on the pressure gradient. At the stationary surface it is equal to U/h minus that term.

The practical use of Lamb's formula, Eq. (24) of Section I, presupposes a knowledge of the velocity gradient throughout the film. The use of Reynolds' formula, Eq. (2) above, requires a corresponding knowledge of the pressure gradient.

MECHANICAL PHENOMENA IN THE FILM.

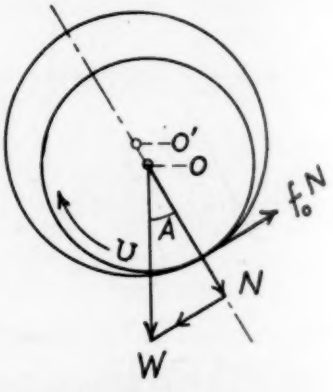
Consider now the state of affairs in a full journal bearing as shown by Fig. 2. The bearing is stationary and the journal

FIG. 2.



Cross section of lubricated bearing, showing displacement in direction of motion.

FIG. 3.



Displacement of the journal in a dry bearing; in opposite direction.

rotating clockwise with a surface speed U. The total load on the journal is W. The radius of the journal, $D/2$, may be denoted by r and the radial clearance, $C/2$, by c. Lubricant is admitted at some point on the unloaded side of the bearing,

and flows through at the rate of Q units of volume per unit time. It will be assumed for the present that the journal is running at a constant speed; that the surfaces are perfectly smooth, rigid, and cylindrical; that the viscosity of the lubricant, μ, is uniform throughout the film; and that any forces acting on the journal due to the supply pressure, or the inertia of the lubricant, are negligible.

Our attention is arrested by the fact that the journal displacement in Fig. 2 is toward the left, in the direction of motion. In a dry bearing the journal would obviously go toward the right, pushing itself uphill, backwards, as shown by Fig. 3 until a point is reached at some angle A with the vertical where the friction on the journal is balanced by the tangential component of the load. The friction, F, is equal to f_0N where f_0 is the coefficient of sliding friction for the surfaces in question, and N is the normal component of the load. Equilibrium occurs when $W \sin A = f_0 W \cos A$, or $\tan A = f_0$. The coefficient, F/W, may be written $f = f_0 \cos A$; and the displacement is in the opposite direction to the motion of the journal. This explanation is so much simpler than the analysis for the lubricated bearing that a convenient rule for determining the direction of displacement of a lubricated journal is to work it out for a dry bearing, and remember it goes the other way.

The anomalous behavior of the lubricated journal is due to the pressure distribution set up. Let o′ denote the center of the bearing, o the center of the journal. The journal is displaced from o′ to o in Fig. 2, through a distance e known as the eccentricity, upon the application of the load W. Let h as before represent the film thickness at any point, while h_0 is the film thickness at the point of closest approach. A positive fluid pressure is developed around the converging half of the film, reaching a maximum somewhere between the line of action of the load and the point of nearest approach. A negative pressure, or suction effect, is created in the remaining half of the film.[2]

[2] The positive and negative pressure regions may be vividly indicated on lecture room charts with the aid of red and blue crayon, respectively. For this purpose Fig. 2 may be reproduced with the outer circle 16 inches, or more, in diameter. The red coloring is to be applied beginning just below the point of

The resultant of all the fluid pressures acting on the surface of the journal balances the load W. To show that this requirement can be met only when the journal is displaced toward the left in Fig. 2, imagine it momentarily in some other position, say with the point of the nearest approach vertically below the center of the bearing. Granting the truth of Reynolds' proposition that a positive pressure can be maintained only in the converging portion of the film, it follows that the excess pressure on the right will push the journal over toward the left until the forces are again in equilibrium.

In the limiting case of an infinitely long bearing, where there is no pressure gradient in the direction of the axis; and when the load is light enough to permit symmetrical positive and negative pressures, Sommerfeld showed that the point of nearest approach will be at right angles to the load (Ref. 3). To a first approximation the shearing stresses may be considered negligible in computing the position of the journal; they are, however, important in calculating pressure distribution and frictional resistance.

If in Fig. 2 a horizontal line be drawn through the center of the bearing, o′, and the upper half of the bearing removed, there can in general be no very great loss in the load carrying capacity of the film since the positive fluid pressures are mainly localized in the bottom quadrant. There will be a considerable reduction in friction, since the area of the journal exposed to the action of shearing stresses has been cut in half. This does not mean that the friction will be quite reduced to one-half, since the part of the film removed was not so thin as the part which remains. It is evident then that a half-bearing should be more efficient than a full-bearing when the line of action of the load is fixed. In practice partial bearings with arcs of 120° or less are not uncommon.

The qualitative reasoning outlined above in connection with the full journal bearing is equally valid when applied to partial bearings, and to the flat pivoted shoes of the modern thrust bearing, with appropriate modifications.

closest approach, reaching a maximum intensity somewhere between this point and the load, then fading off into an invisible pink. No coloring should be applied where the line of centers intersects the film, since these points are in regions of practically zero pressure, measured relatively to the supply pressure.

DEFINITIONS OF LOAD CAPACITY.

In discussing load capacity or permissible bearing pressure, P_0, it is understood that the requirements of strength and rigidity have been satisfied before investigating lubrication conditions. There remain at least four criteria, any of which might be adopted as the basis for a working definition of load capacity. These are (1) heat development, (2) film failure, (3) stability of lubrication, and (4) film thickness.

The rate of heat development in a bearing is proportional to the product of the coefficient of friction, f; the load, W; and the surface speed (in the older notation), V. The rate per unit area is proportional to fPV, where P is the bearing pressure, or load per unit of projected area. In accordance with Coulomb's law, the coefficient is generally assumed to be a constant for imperfectly lubricated surfaces. For such bearing surfaces the condition for a fixed rate of heat development per unit area would be correctly given by Thurston's rule, PV = Constant. Hence the load capacity, P_0, would be inversely proportional to V.

Film failure, or metallic contact, might be recognized in several ways. It is usually identified with seizure, although the distinction between true and apparent seizure is sometimes overlooked, the latter corresponding merely to a high value of the friction torque. Load capacity definitions based on film failure have been proposed or implied in connection with the comparative testing of E.P. (extreme pressure) gear lubricants.[3]

The coefficient of journal friction passes through a minimum value when the speed, load, or viscosity of the lubricant is sufficiently varied (Ref. 3). The approximate location of this minimum point may be determined experimentally for any given type of bearing and has been adopted by Wilson and Barnard, McKee, and others (Refs. 20, 32) as a criterion for load capacity. At the right of the minimum point the condition is described as stable lubrication. Any increase of friction with consequent rise of temperature is self-correcting, because the reduction in viscosity tends to

[3] Film failure was more fully discussed in the lecture on "Imperfect Lubrication."

reduce the friction. At the left, where the curve slopes the other way, the same reduction in viscosity would cause an increase in friction. The heat so developed would further increase the friction. This action would perpetuate itself. Thus the minimum point marks a transition between stable and unstable lubrication (Ref. 20). The critical bearing pressure P_0 corresponding to the minimum point may be taken as the maximum load capacity. In practice this value is to be divided by a factor of safety. The effect of running-in a new bearing is to shift the minimum point toward the left (Ref. 32), thereby increasing the factor of safety.

Finally the load capacity may be defined in terms of film thickness at the point of nearest approach. A certain numerical value such as five ten-thousandths of an inch, increasing with diameter and roughness of finish, is arbitrarily agreed upon as a safe limit (Refs. 28, 45, 52). The load capacity is then defined as the bearing pressure which will squeeze the film down to the thickness in question. This criterion is diametrically opposed to the PV = Constant rule, in that it permits greater loads at the higher speeds. The load corresponding to any desired thickness, or vice versa, may with some difficulty be determined experimentally. Many such investigations have been made.[4] It appears to be the practice now of the larger companies manufacturing the modern types of bearings to base their designs directly on the hydrodynamic theory. Therefore in what follows, the film thickness criterion will be used.

The importance of knowing the load capacity or carrying power of any proposed bearing is evident from the example at the end of the last Section, where it was found that the friction when lightly loaded was proportional to the length.[5] In economizing on power and space requirements by shortening the bearing a point may be reached where the gain is more than offset by the increased friction per unit length due to eccentricity, as well as by the risk of injury to the bearing surfaces.

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[4] Quantitative results were discussed in a subsequent lecture on "Experimental Data." For original sources see Ref. 49.

[5] See also pp. 167–169 of Ref. 11.

REYNOLDS' EQUATION FOR PRESSURE DISTRIBUTION.

Under steady running conditions such that the surface speed U and the film thickness h at any point are constant with respect to the time, and when using an incompressible lubricant, the general equation of the hydrodynamic theory (Ref. 1) may be written

$$\frac{\partial}{\partial x}\left(\frac{h^3}{12\mu}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{h^3}{12\mu}\frac{\partial p}{\partial z}\right)=\frac{U}{2}\frac{\partial h}{\partial x}, \tag{7}$$

in which μ is the viscosity, and p the hydrostatic pressure, at any point in the film whose coördinates are x and z. The coördinate x is measured in the direction of motion, i.e. parallel to U, while z is at right angles. Thus in a journal bearing z represents distances parallel to the axis of the shaft.

In deriving Eq. (7) we start with an element of the fluid having a base $dxdz$ as in Fig. 1, but a height h extending all the way from the stationary to the moving surface. To determine the pressure distribution in the immediate vicinity of the element $hdxdz$ we must utilize the equation of continuity. Let Q_x and Q_x' denote respectively the quantity of fluid per unit time flowing into and out of the volume element in the x-direction, while Q_z and Q_z' denote the corresponding rates of flow in the z-direction. If the fluid is incompressible, the same volume that goes into the box on two sides must flow out across the other two sides, hence for the equation of continuity $Q_x' + Q_z' = Q_x + Q_z$. Since, however, in mathematical notation Q_x' may be written $Q_x + (\partial Q_x/\partial x)dx$, with a similar expression for Q_z', the equation becomes

$$\left(\frac{\partial Q_x}{\partial x}\right)dx+\left(\frac{\partial Q_z}{\partial z}\right)dz=0. \tag{8}$$

The rate of flow Q_x may be found by integrating the velocity u from $y = 0$ to $y = h$, and multiplying by dz. Evidently from Fig. 1 (b) the expression will consist of two parts, one corresponding to the linear distribution u_1 and the other to the parabolic distribution u_2. The first term is equal to the mean velocity $U/2$ multiplied by the area hdz. The second term is equal to $-(h^3/12\mu)$ into the pressure gradient $\partial p/\partial x$ multiplied by dz. The steps required in proving this are

identical with those previously used in deriving Poiseuille's law, except that we are here dealing with viscous flow between two nearly parallel planes of width dz, separated by a distance h.

$$\therefore \quad Q_x = \left(\frac{U}{2}\right) h dz - \frac{h^3}{12\mu}\left(\frac{\partial p}{\partial x}\right) dz. \tag{9}$$

In a journal bearing this quantity Q_x represents the rate of flow of the lubricant in a circumferential direction. An expression for Q_z, corresponding to the well known side leakage effect, may be written down by analogy, keeping in mind that there is no relative motion of the bearing surfaces in the z-direction;

$$\therefore \quad Q_z = -\frac{h^3}{12\mu}\left(\frac{\partial p}{\partial z}\right) dx. \tag{10}$$

Substituting from (9) and (10) into (8) leads immediately to Eq. (7).

Reynolds integrated the equation for the case of negligible side leakage by setting $\partial p/\partial z = 0$ and treating the viscosity as a constant. Under these conditions we obtain by a single integration

$$\frac{dp}{dx} = 6\mu U\left(\frac{h - h_1}{h^3}\right). \tag{11}$$

The constant of integration h_1 is the value of the film thickness, h, at the point of maximum pressure; i.e., where $dp/dx = 0$. Further integration of (12) requires an expression for the film thickness as a function of the distance, x, in the direction of motion. For flat surfaces h is a linear function of x. Reynolds completed the solution for flat surfaces of infinite width, and for the partial bearing of Tower's experiments under conditions such that the eccentricity would not exceed one-half the radial clearance.

SOMMERFELD'S THEORY.

Dr. A. Sommerfeld of Munich succeeded in integrating Reynolds' equation for all values of the eccentricity, and in extending the solution to the half bearing and the full bearing (Refs. 3, 9, 18 and p. 165 of Ref. 46). Sommerfeld's paper of

1904 is a masterpiece of mathematical skill combined with clearness of exposition.

The assumption of infinite width, or negligible side leakage, was retained so that the analysis might start from Eq. (11), which with $x = r\theta$ becomes

$$\frac{dp}{d\theta} = 6\mu Ur\left(\frac{h - h_1}{h^3}\right). \tag{12}$$

In Eq. (12) r denotes the radius of the journal while θ is measured around the bearing from the line of centers in the direction of motion, so that in the case of a full bearing $\theta = 0$ at the point of maximum film thickness.

For the journal bearing of radial clearance c it may easily be shown that

$$h = c + e\cos\theta = e(\alpha + \cos\theta), \tag{13}$$

where e is the eccentricity (Fig. 2) and α denotes the ratio c/e, which can vary from one (for metallic contact) up to infinity (for a perfectly concentric bearing). Substituting from (13) into (12) and integrating gives for the pressure difference $p - p_0$ at any angular position θ,

$$p - p_0 = \frac{6\mu Ur\alpha^2}{c^2}\left[J_2(\theta) - \frac{h_1}{e}J_3(\theta)\right]. \tag{14}$$

In (14) the constant of integration p_0 represents the atmospheric pressure or any other pressure arbitrarily maintained at $\theta = 0$. The functions J_2 and J_3 are defined by

$$\left.\begin{aligned} J_2(\theta) &= \int_0^\theta \frac{d\theta}{(\alpha + \cos\theta)^2}, \\ J_3(\theta) &= \int_0^\theta \frac{d\theta}{(\alpha + \cos\theta)^3}; \end{aligned}\right\} \tag{15}$$

from which it will be seen that $J_2(0)$ and $J_3(0)$ are equal to zero.

To evaluate the constant of integration h_1 Sommerfeld makes use of the fact that p as a function of θ must have identical values at $\theta = 0$ and $\theta = 2\pi$, hence from (14)

$$\frac{h_1}{e} = \frac{J_2(2\pi)}{J_3(2\pi)} = \frac{2\alpha(\alpha^2 - 1)}{2\alpha^2 + 1}. \tag{16}$$

This last expression may be substituted for h_1/e in Eq. (14), giving the desired equation for the pressure distribution corresponding to any particular eccentricity.

In determining the load W for which any assumed value of α would represent a position of equilibrium, Sommerfeld first points out that, in the case of a full journal bearing, the resultant of the fluid pressures acts at right angles to the line of centers. In other words, the journal displacement is at right angles to the load. This is true only when side leakage can be neglected, and results from the fact that the pressure distribution under these conditions is symmetrical with respect to the line of centers, as shown by Eq. (12). Sommerfeld then evaluates W by equating it to the integral of the vertical components of the fluid pressures on the journal, i.e.,

$$\int_0^{2\pi} p \sin\theta \cdot Lrd\theta = W, \tag{17}$$

where L is the length of the bearing and r the radius of the journal. Integrating by parts and substituting from the previous equations he obtains for the full bearing

$$\frac{12\pi\alpha^2}{(2\alpha^2+1)\sqrt{\alpha^2-1}} = \left(\frac{c}{r}\right)^2 \frac{W}{\mu UL}. \tag{18}$$

Replacing dp/dx in Eq. (2) by its equivalent $(1/r)dp/d\theta$, and h by its equivalent from (13), an expression is obtained for the shearing stress on the journal surface in terms of the eccentricity reciprocal, α. Integrating and dividing by the load gives for the coefficient of friction

$$f = \frac{c}{r}\left(\frac{\alpha^2+2}{3\alpha}\right). \tag{19}$$

The pressure distribution formulas (14) to (16) above, Equation (18) for journal running positions, and Eq. (19) for the coefficient of friction contain the principal results of Sommerfeld's investigation as applied to the full journal bearing. These same results may be expressed in other forms for convenience in lubrication calculations, and will be further discussed below.

OTHER MATHEMATICAL INTEGRATIONS.

A three dimensional solution for rectangular plane surfaces, including side leakage, was published by A. G. M. Michell of Melbourne in 1905 (Ref. 4). This was immediately applied in the design of thrust bearings, and has also been interpreted as providing a first approximation to the side leakage effect in journal bearings. The pressure distribution computed for a square slide block of length π is shown by the smooth curves in Fig. 5. Here p/C denotes the ratio of the pressure at any point in the film to the constant $6\mu U/c^2$, where c is the sine of the angle of inclination between the two plane surfaces, and distances are measured from their intersection. Michell's theory has been further extended and applied by H. M. Martin, R. O. Boswall, T. Kobayashi, and others (Refs. 10, 17, 22, 33, 50).

No corresponding solution for journal bearings by direct mathematical integration has yet been forthcoming, although many approximate solutions have been proposed. We have seen that the usual approximation consists in treating the bearing as one of infinite width, by omitting the term containing $\partial p/\partial z$ in Eq. (7). Interesting solutions have been worked out by Michell, Cardullo, and Rouse for infinitely narrow bearings by omitting the term containing $\partial p/\partial x$ while retaining the other terms in Reynolds' equation (Refs. 4, 39, 41, and p. 162 of Ref. 46).

Approximate formulas for the journal bearing of finite width were published by L. Gümbel in a series of papers beginning in 1914 (Ref. 25). These were based on Michell's solution for plane surfaces and on Kingsbury's experiments with the air lubricated journal. A sine curve was adopted to represent the transverse pressure distribution. Karelitz in a similar investigation used a parabola (Ref. 26). Gümbel's calculations have been further extended by Orloff (Ref. 53) and applied to the full journal bearing. Orloff's theory is apparently in excellent agreement with Barnard's experiments on oil flow, and with the experiments of McKee and others on friction.

It was shown by Dr. A. Stodola of Zurich (Ref. 19) that Reynolds' equation (7) might be solved by successive approximations, assuming the pressure distribution function $p(x, z)$

could be represented by the product of two factors, one of which is a function of x alone and the other a function of z alone. Such methods have been further developed by Boswall and by Duffing (Refs. 33, 42) and applied to both thrust and journal bearings.

Howarth, in a series of papers beginning in 1923, showed how Reynolds' equation (12), for journal bearings of infinite width, might be integrated graphically to obtain the necessary solutions for a wide variety of partial bearings (Refs. 22, 29, 38). Analytical solutions for many of these problems were afterwards derived by Boswall (Ref. 33) and by Kingsbury (Ref. 45).

Sommerfeld's theory was critically re-examined and confirmed by Harrison and by Duffing (Refs. 7, 24). It was modified by Gümbel to take into account the location of the oil inlet, and the practical interpretation of the theoretical negative pressures (Ref. 25). Skinner had verified experimentally the occurrence of cavitation in the film (Ref. 5). Swift concluded that the integrations should not be carried beyond the point where the negative pressure begins (Ref. 47). Merely to disregard the region of negative pressure after first integrating over the entire bearing arc would lead to a different, and incorrect result. This view was carried a step farther by Robb (Ref. 48).

Steady states have ordinarily been assumed; and to date (1935), no theoretical solution has been found in the literature directly applicable to the automotive engine and other reciprocating mechanisms. The effect of fluctuating loads on the journal was, however, considered by Harrison (Ref. 16); while shaft oscillations due to the yielding of the oil film were investigated by Stodola and by Hummel (Refs. 27, 30).

In most of the investigations outlined above the simplest possible assumptions are made regarding the physical properties of the lubricant; the viscosity being treated as a constant, and the density and compressibility assumed negligible. The effect, on lubrication performance, of the change in viscosity with pressure has been discussed by Stanton (Ref. 23), Kiesskalt (Ref. 31), and Waters (Ref. 36), although no integration of Reynolds' equation treating the viscosity as a function of pressure has been published. The importance of

taking into account both the change in viscosity with temperature, and the inertia of the lubricant was emphasized by Kingsbury at the 1927 annual meeting of the American Society of Mechanical Engineers (Ref. 35). Boswall in his treatise of 1928 integrated Reynolds' equation on the assumption that the viscosity is a linear function of the distance from the leading edge of the film (Ref. 33). The effect of the inertia of the lubricant was investigated by Brillié (Ref. 34) with special reference to the lubrication of parallel surfaces. It was necessary to modify Reynolds' equation by introducing a term $\rho u^2/2$ for the dynamic pressure, where ρ is the density and u the velocity at any point of the film.

The effect of compressibility had been investigated by Harrison in the earlier of the two papers cited (Ref. 7). As a result he was able to show that Sommerfeld's theory, corrected for compressibility, is in excellent agreement with Kingsbury's experiments on the air lubricated journal.

ELECTRICAL INTEGRATION.

A precise solution of the side-leakage problem was finally achieved by Albert Kingsbury, with the aid of an electrical analogy (Ref. 44). The method is applicable to variable as well as uniform viscosity, and provides for certain effects due to the inertia of the lubricant. As described by Dr. Kingsbury,

"The method . . . consists primarily in direct experiment upon large-scale electrically conducting models, each so designed that the space relations of current and voltage are very nearly the same as those of volume flow and pressure in lubricating films of arbitrarily assumed form and viscosity variation.

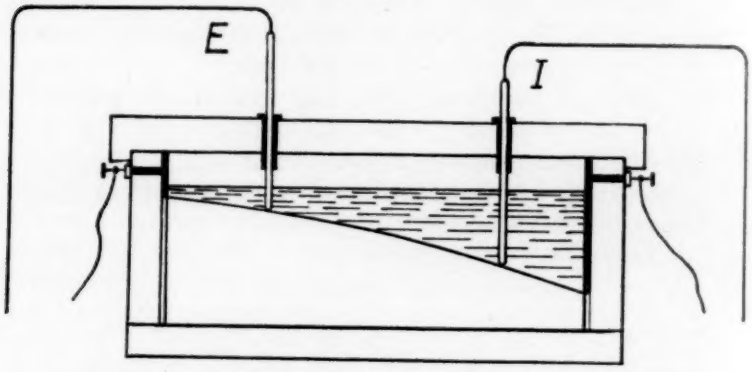
"The general arrangement of the model consists of a body of fluid of low electrical conductivity, with free upper surface, to any desired scale; the varying depth of the bath is determined by a wooden form fastened in tbe box. . . . Metal plates inserted at the sides provide means for establishing potentials corresponding to pressure conditions at the edges of the bearing film. Metal-rod electrodes, inserted vertically to the full depth of the bath at chosen points, furnish means for supplying current, corresponding to volume flow in the oil film, and for measuring voltage, corresponding to pressure in the oil film (Fig. 4).

"For present purposes, the basic differential equation for the oil film may be written . . .

$$\frac{d}{dx}\left(\frac{h^3}{\phi}\frac{dp}{dx}\right)+\frac{d}{dz}\left(\frac{h^3}{\phi}\frac{dp}{dz}\right)=12\mu_0 q \qquad (20)$$

in which μ_0 is the viscosity at a base point, and ϕ a non-dimensional function of x and z such that the viscosity at any point is given by $\phi\mu_0$, and q represents any or all of the terms on the right.[6] . . .

FIG. 4.



Large scale model of oil film (E, potential measuring electrode; I, current carrying electrode; cf. Ref. 44).

"In order to establish working equations for the experimental method, we have first to consider that just as viscous flow is proportional to the pressure gradient and inversely as the viscosity, so is current flow proportional to the potential gradient and inversely as the resistivity (Ohm's law). There is, however, this difference: that the viscous flow is proportional to the third power of the film thickness, while the current flow is proportional to the first power only. Thus . . . in the model,

$$\frac{d}{dx}\left(\frac{H}{r}\frac{dE}{dx}\right)+\frac{d}{dz}\left(\frac{H}{r}\frac{dE}{dz}\right)=i=(\text{approx.})\frac{I}{\alpha}, \qquad (21)$$

in which H is the variable depth of the bath, r is the uniform resistivity, E the potential, i the current supplied per unit area.

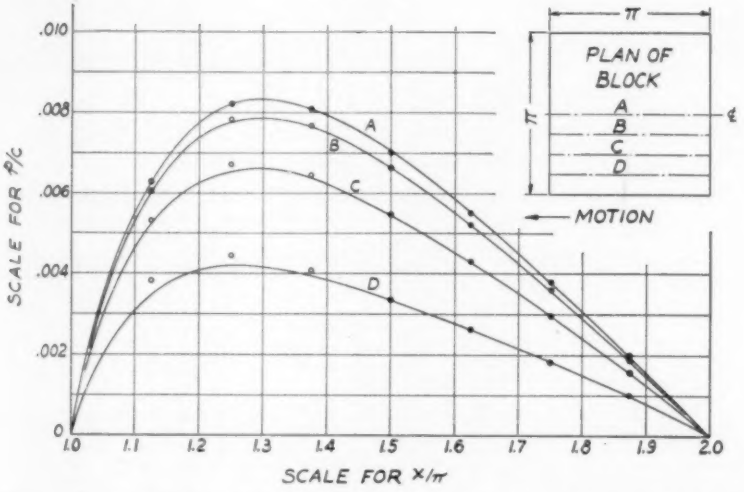
[6] The right hand side of Eq. (7), as originally expressed by Reynolds, included a term V for the normal component of the relative velocity of the two surfaces; and might be generalized, as shown by Kingsbury, to include other volume displacement effects such as those due to thermal expansion and centrifugal action.

Like Eq. (7), this is an equation of continuity; it is the symbolized statement of the equality of the inflow and the outflow of current, with reference to a single elementary volume of the bath, of unit-area base and of height H. The reason for the expression I/α is that in the experiment it is not generally practicable to deal directly with unit areas; the whole area is divided into an arbitrary number of (preferably equal) areas α, and a current I is supplied at the center of each of these areas successively. . . .

"Comparing (20) and (21), it is evident that if we were to make, numerically, $H = h^3/\phi$ and $Ir/\alpha = 12\mu_0 q$ at all points, then a complete experimental solution of (21) for the numerical value of E at any point would give also the numerical value of p at the same point. . . ."

A typical comparison of the results of Kingsbury's method with values calculated by Michell is shown in Fig. 5 for one

FIG. 5.



Pressure distribution on a square slide block (Fig. 5-A of paper by Albert Kingsbury, Ref. 44).

of the very few cases where complete mathematical solutions are available. Twenty-eight points were found sufficient on account of the symmetrical distribution of the pressure. This arrangement of points, however, required a total of 896 observations each of current and voltage since, as explained in the paper, for each position of the electrode used in ex-

ploring the potential distribution, the current electrode must be placed in a succession of different positions and the results obtained by the principle of superposition. Reference should be made to the original paper for further details, and for a number of important applications to thrust and journal bearings.

LUBRICATION PERFORMANCE CALCULATIONS.

The steps to be taken in applying the hydrodynamic theory may be illustrated by a study of Sommerfeld's results for the full journal bearing. The same general procedure would be applicable in the investigation of partial bearings, thrust bearings, and gear teeth under fluid film conditions.[7]

The film thickness, h_0 or x, at the point of nearest approach may be expressed as a fraction of the radial clearance, x/c, and can be calculated from Eq. (18). This may be rewritten more conveniently [8]

$$\frac{\mu N}{P}\left(\frac{D}{C}\right)^2 = \frac{(2\alpha^2+1)\sqrt{\alpha^2-1}}{12\pi^2\alpha^2}, \tag{22}$$

upon substituting D/C for r/c, PDL for W, and πDN for U. The value of α corresponding to any particular value of x/c may be found from $\alpha = c/e$ and $x = c - e$. In this manner the curve shown by Fig. 6 has been plotted from Eq. (22); and gives the relative film thickness, x/c, as a function of the Sommerfeld variable, defined by

$$s = \frac{\mu N}{P}\left(\frac{D}{C}\right)^2. \tag{23}$$

For the location of the maximum and minimum pressures, we find from (13) on setting $h = h_1$ and $\theta = \theta_1$ that $\cos\theta_1 = (h_1/e) - \alpha$, hence with the aid of (16)

$$\cos\theta_1 = -\frac{3\alpha}{2\alpha^2+1}. \tag{24}$$

The two points are thus equally distant from the line of centers, being 180° apart in a concentric bearing ($\alpha = \infty$)

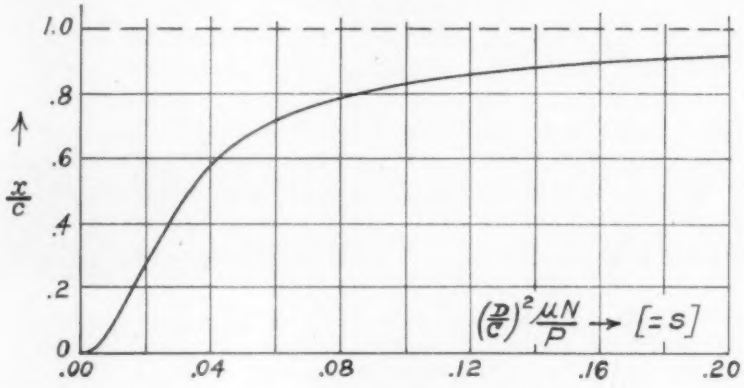
[7] See Refs. 6, 13–15, 37 in addition to those previously cited.

[8] See Eq. (69) of Ref. 11 for the complete expression in terms of x/c, keeping in mind the distinction between the radial clearance c and the total clearance C.

but approaching coincidence at the point of minimum film thickness as the journal approaches contact with the bearing ($\alpha = 1$). It will be recalled that the angle θ is measured from the line of centers in the direction of motion, starting with $\theta = 0$ at the point of maximum film thickness.

Replacing U by $2\pi rN$ and r/c by D/C in Eq. (14), substituting from (15), (16) and (22), and evaluating the integrals

FIG. 6.



Relative film thickness, x/c, as a function of the design and operating variables for a full journal bearing without side leakage.

gives for the relative film pressure at any point around the circumference

$$\frac{p - p_0}{P} = \frac{\sqrt{\alpha^2 - 1}(2\alpha + \cos\theta)\sin\theta}{\pi(\alpha + \cos\theta)^2}. \qquad (25)$$

While for most purposes this equation may be used as it stands, it should also be possible to eliminate α between (22) and (25) by graphical methods; and then plot a family of curves giving the relative film pressure as a function of the Sommerfeld variable for any fixed value of θ.

Eliminating α between Eqs. (19) and (22) in this manner gives a direct relation between the coefficient of friction and the Sommerfeld variable, which has been plotted in Fig. 7.

The load capacity may be calculated from Eq. (22) by setting $P = P_0$ when $\alpha = \alpha_0$, this value corresponding to the minimum safe film thickness $x = x_0$. Making these

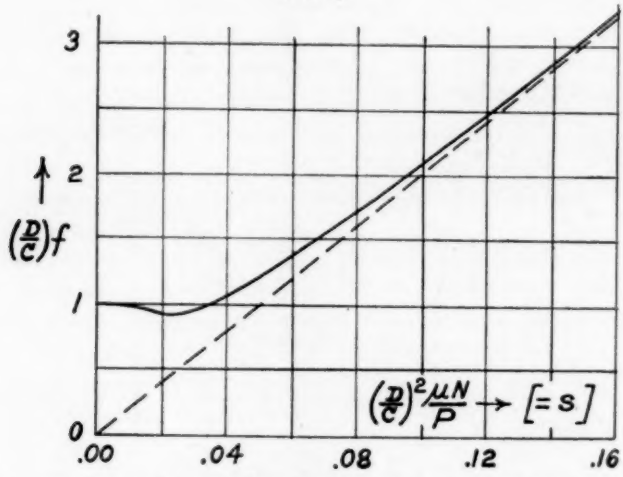
substitutions and letting s_0 denote the corresponding value of the Sommerfeld variable,

$$P_0 = \frac{\mu N}{s_0}\left(\frac{D}{C}\right)^2 = \text{const. } \mu N; \tag{26}$$

hence for a given bearing the load capacity is directly proportional to the product of the viscosity into the speed.

The foregoing calculations presuppose the maintenance of a supply pressure p_0 at $\theta = 0$ not less than the maximum value of the pressure difference computed from Eq. (25).

FIG. 7.



Relation connecting the coefficient of friction, f, with the design and operating variables for a full journal bearing under the Sommerfeld conditions.

In actual bearings of finite width L the application of such pressures may induce an excessive rate of oil flow. To estimate this rate, Q, for a concentric bearing we may assume, as a first approximation, that it is due to a pressure uniformly distributed around the circumference, equal to p_0 at the middle point $z = 0$, and equal to p_1 at the outlet $z = \pm L/2$; and that the distribution in the z-direction is parabolic (Ref. 26). The foregoing defines a pressure distribution

$$p = p_0 - 4(p_0 - p_1)\left(\frac{Z}{L}\right)^2; \tag{27}$$

from which the gradient at the outlet, $\partial p/\partial z$, is equal to $-4(p_0 - p_1)/L$. Substituting into Eq. (10), together with $h = C/2$ and $dx = \pi D$; and writing $Q = 2Q_z$ to allow for flow in both directions,

$$Q = \frac{\pi}{24}\left(\frac{C}{D}\right)^3 \frac{D^4}{\mu}\left(\frac{p_0 - p_1}{L}\right). \tag{28}$$

More precise formulas will be found in the paper by Orloff, Ref. 53.

We are now in a position to examine more closely the numerical example given in Section I, for which the data were briefly as follows: Length (or width) L, 6 inches; diameter, D, 3 inches; clearance ratio, $C/D = 1/1000$; speed, N, 1200 r.p.m. or 20 revolutions per second; load, W, 720 pounds, or bearing pressure P, 40 pounds per square inch; viscosity, μ, at the assumed film temperature, 30 centipoises or 4.35×10^{-6} pound seconds per square inch. The performance calculations of immediate interest are (1) film thickness, (2) film pressure, (3) oil flow, (4) load capacity, and (5) friction loss.

(1) In the solution by Petroff's formula it was assumed that the film thickness was uniform, and equal to the radial clearance, 0.0015 inch; or that the relative film thickness, x/c, is equal to one. From Fig. 6 it will be recalled that the relative film thickness depends only upon the Sommerfeld variable, s, defined by Eq. (23). For the data given, $s = 2.18$. This lies so far to the right that the curve must be very close to the asymptote, $x/c = 1$. Eq. (22), simplified for large values of α, gives $\alpha = 6\pi^2 s = 129$. Therefore $x/c = 1 - (1/\alpha) = .992$, confirming the original assumption within one per cent. when side leakage is disregarded.

(2) From Eq. (25) we find for the relative film pressure, when α is so large that the journal is practically concentric, $(2/\pi)\sin\theta$. The maximum value, $2/\pi$ or .64, occurs when $\theta = \theta_1 = 90°$, i.e., directly under the load. The value is zero at $\theta = 0°$ and 180°. With $P = 40$ pounds per square inch, this result indicates that the absolute pressure p increases from p_0 to $p_0 + 25.6$ pounds per square inch in passing around the first quarter of the circumference. It decreases to p_0 at the end of the second quadrant; and to $p_0 - 25.6$ pounds per square inch at the top of the bearing. To insure against an incomplete film due to negative pressures, the supply pressure at $\theta = 0$ should not be much less than 25.6 pounds per square inch gage pressure.

(3) The rate of oil flow due to a mean pressure difference of 26 pounds per square inch may be estimated roughly from (28) and amounts to 0.0107 cubic inch per second, or about 38 cubic inches per hour from each bearing.

(4) To calculate the load capacity for a safe film thickness arbitrarily taken equal to half the radial clearance, or 0.00075 inch, we read from Fig. 6 for $x/c = 0.5$, $s = s_0 = 0.034$. Substituting in Eq. (26) gives for the load capacity, P_0, of a complete film approximately 2500 pounds per square inch.

(5) For the friction coefficient when $\alpha = 129$ we have from Eq. (19), simplified for large values of α, $f = (C/D)\alpha/3 = 0.043$. This agrees with the value computed from Petroff's equation in Section I. The friction loss was found to be 0.88 horsepower per bearing. Under a load of 2500 pounds per square inch, however, ($s = .034$), the coefficient drops to 0.001, as may be seen from Fig. 7. This is about 30 per cent. greater than the value computed from Petroff's equation, represented by the asymptotic straight line in Fig. 7.

To vary the conditions of the problem consider a journal 10 inches in diameter running in a bearing 10 inches long at 1500 revolutions per minute, carrying a load of 25,000 pounds, with a clearance of 0.0015 inch per inch of diameter; the viscosity being the same.

Proceeding as before, $s = 0.193$, hence from Fig. 6 the film thickness is 0.91 of the radial clearance, or 0.0068 inch, and $\alpha = 11.1$. Then from Eq. (24) the maximum pressure is located at $\theta_1 = 98°$, nearly; and exceeds the supply pressure according to Eq. (25), by 0.63 of the bearing pressure, or 158 pounds per square inch. To maintain a complete film therefore requires a gage pressure of about 158 pounds per square inch at the oil inlet. The corresponding flow from the two ends of one bearing is of the order of 17 cubic inches per second. The load capacity for a minimum film thickness equal to half the radial clearance would be about 1040 pounds per square inch, but might involve an excessive rate of oil flow. The coefficient of friction from Fig. 7 is equal to 0.0059 with the original loading of 250 pounds per square inch, or just perceptibly greater than the Petroff value taken from the asymptote of the curve. From Eq. (21) of Section I, the friction loss of this bearing will therefore amount to 9700 foot pounds per second, or about 18 horsepower (Table I).

When the requisite supply pressure is not available the actual performance of a full bearing is more nearly represented by the calculated performance of a half bearing (Refs. 3, 21, 28).

COMPARISON OF TWO SOLUTIONS FOR A PARTIAL BEARING.

Passing over the many interesting approximate solutions for the half bearing and other partial bearings available in the literature, we may consider the problem of the 120° centrally loaded bearing with running clearance, which has recently been worked out in more detail. This type appears to be one of the most efficient designs for the larger sized bearings carrying steady loads.

A solution on the classical assumption of a complete film with negligible side leakage was published by H. A. S. Howarth beginning in 1923. The results given in the fifth column of

Table 1 were obtained from his graphical analysis (Ref. 21). No change has been made in the conditions of the problem other than the substitution of the 120° arc in place of the full bearing. This change, it will be seen, increases the eccentricity and diminishes the film thickness. The maximum film pressure is increased. The load capacity is reduced. There is, however, a considerable saving in friction, and the relatively high supply pressure assumed in the Sommerfeld theory of the full bearing is no longer required.

TABLE 1.

Four Solutions for a Ten Inch Bearing.

($C/D = 0.0015$, $L/D = 1$, $\mu = 30$ centipoises or 4.35×10^{-6} pound seconds per square inch, $N = 1500$ revolutions per minute, $W = 25{,}000$ pounds, $P = 250$ pounds per square inch.)

Quantity.	Unit.	Full Bearing.		120° Bearing.	
		Petroff (1883).	Sommerfeld (1904).	Howarth (1923).	Needs (1934).
Relative eccentricity	%	0	8.7	35	56
Min. film thickness	Inch	.0075	.0068	.0049	.0033
Max. film pressure[a]	Lb./in.^{2}	0	155	440	710
Load capacity[b]	Do.	—	1040	350	180
Friction coefficient	—	.0057	.0059	.0032	.0037
Power loss	H.P.	17.0	17.6	9.5	11.0

[a] In excess of supply pressure. [b] Relative eccentricity 50 %.

The corresponding results from an investigation by S. J. Needs (Ref. 51) based upon Kingsbury's electrical integration method are given in the final column of Table 1. A comparison of the last two columns shows that the effect of side leakage is to reduce the film thickness and load capacity by considerable amounts, while slightly increasing the friction.[9]

EXPERIMENTAL DEMONSTRATIONS OF FILM FORMATION.

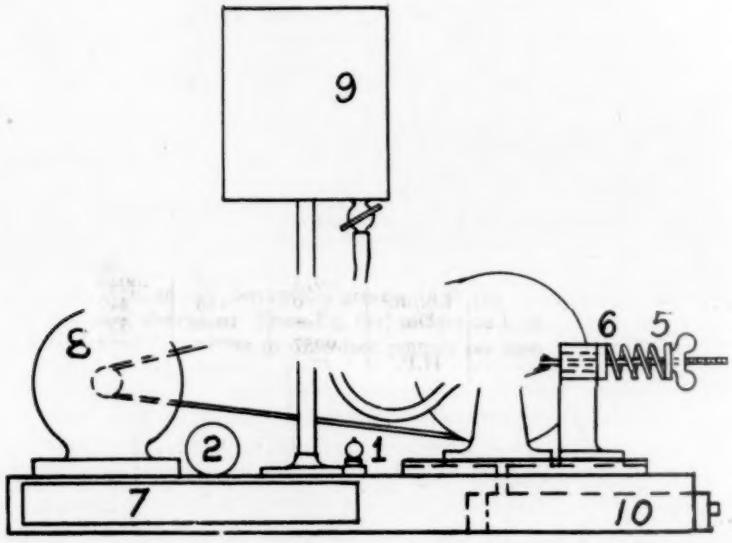
The increasing electrical resistance of the oil film in a partial bearing when the speed is increased at constant load was demonstrated by H. F. Moore in 1903 (Ref. 2). This method was applied to a full bearing by the present author (Ref. 8)

[9] A comprehensive discussion of bearing design problems will be found in the recent paper by Howarth, Ref. 52.

and has been further developed by other investigators (Refs. 12, 49). It remained for S. A. McKee of the Bureau of Standards to apply the electrical resistance principle to the journal bearing in a sufficiently ingenious form to provide a convincing lecture table demonstration (Ref. 40).

In the McKee apparatus, or bearing lubrication indicator,[10] a dry cell and flash light bulb are connected in series with the oil film. The test journal, of about 3/4 inch diameter, is mounted horizontally in two supporting bearings (Fig. 8).

FIG. 8.



McKee lubrication indicator (1, lamp; 2, dry cell; 3, test bearing; 4, oil inlet; 5, loading spring; 6, insulation; 7, rheostat for speed control; 8, d.c. motor; 9, oil supply; 10, used oil).

The test bearing is a full bearing of bronze, about one inch long, loaded horizontally by a helical spring. The tension of the spring is varied by turning a wing nut. Oil is fed by gravity through a flexible rubber tube to an oil inlet at the middle of the length of the bearing. The angular position of the oil inlet can be varied at will by twisting the bearing around. The speed is varied by means of a sliding rheostat

[10] Loaned for the lectures in Providence and New Haven through courtesy of the National Bureau of Standards.

in the armature circuit of the d.c. driving motor. This motor is a small one of about 1/8 horsepower, belted to a large pulley on the test shaft so as to reduce the speed.

At low speeds and heavy loads, or with an unfavorable position for the oil inlet, the lamp flashes on, indicating metallic contact. By sufficiently reducing the load, increasing the speed, or by turning the oil hole away from the loaded area toward a region of lower film pressure, the lamp is made to go out, indicating the formation of a true hydrodynamic film.

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A Useful Electron Tube Manual Regulator.—P. H. CRAIG (*Power Plant Engineering*, Vol. 34, No. 6). The "Kathetron" tube regulator can be used for any A.C. circuit where it is desired to manipulate voltage, in fact, wherever rheostats, resistances, reactances, multi-step transformers and similar apparatus is ordinarily used. The tube is essentially a hot cathode gas filled regulator tube of the grid controlled type, a hot cathode rectifier. The grid, however, takes the form of a metal band externally surrounding the bulb. With this structure the time permitted the positive current pulse to pass is varied by varying the potential applied to the grid without shifting the phase. The grid prevents the striking of the arc between the cathode and anode until a later point in the positive alternation. The phase relationship is kept constant and the amplitude of the voltage on the grid is varied to produce complete control of the current which flows through the tube. Due to the fact that the grid requires practically no current for its operation, Kathetron tubes are well adapted to remote control of any kind.

R. H. O.

Boiling a Ship.—(*Fuel*, Vol. 14, No. 5.) Excerpts from *The Observer* show an interesting example of the ingenuity of shipyard people in the boiling of a steamer in a Tyne dock recently. Oil had congealed in the bilges and tanks, and resisted all the known methods of removal. The only apparent method of getting rid of the solidified oil was to open up the ship and dig the mass away, an expensive operation. However, it was determined to try heating the whole ship. She was taken into a drydock, which was flooded to the height of the obstinate bilges. Then every available boiler on the dockside was set going, and steam pipes were led into the water. The water was heated sufficiently to melt the oil through the thickness of the ship's skin.

R. H. O.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

PLASTIC CAULKING MATERIALS.

Plastic caulking materials comprise a class of products which has, during recent years, aided materially in solving one of the inherent problems in the construction of masonry buildings. Although the sealing of joints between masonry and door or window frames constitutes a large part of the use of the plastics there are numerous other similar purposes which they serve in building construction.

Being a comparatively recent addition to the list of building materials, there is much to be learned about the composition, fabrication, and control of the product for the varied service conditions to which it is exposed.

A few years ago the Bureau was confronted with the task of devising a means for determining the quality of such materials. The nature and uses of the product were such that tests or equipment commonly used on other types of building materials were not applicable. New test procedures had to be developed and the necessary testing apparatus designed.

Four types of tests are now used and are intended to determine qualities having a bearing on service performance. They have been in use for four years and a large number of samples have been tested for government jobs. The "strain test" determines if the material remains sufficiently plastic in a joint to accommodate itself to structural movements which vary with the width of the joint; "staining tests" determine if the plastics discolor masonry near the joint and also give information on the performance of the material; "slump tests" determine if the materials will become too soft in summer and flow out of the joints; and "copper corrosion tests" are supposed to indicate certain undesirable properties of the plasticizing ingredients.

*Communicated by the Director.

A detailed description of the various tests and the laboratory equipment was presented at the June meeting of the American Society for Testing Materials.

HIGH EARLY STRENGTH CEMENTS.

Tests have recently been completed at the Bureau on a number of commercial high early strength portland cements. Concretes made from the cements with different amounts of water were stored under various temperature conditions during the first twenty-four hours after making and under various temperature and moisture conditions afterwards. Samples of concrete were subjected to treatments simulating weather conditions, such as freezing and thawing, and drying and soaking. Mortars of various types were also studied and their strengths compared with those of concretes containing different amounts of water.

All of the cements gave early strengths higher than those of ordinary portland cements. It was found that temperatures higher than normal 21° C. (70° F.) and up to 43° C. (110° F.) greatly increased the early strengths (up to three days) of the concretes. Later strengths depended on the cement and on the presence of moisture; the samples kept wet gave the highest strengths. Three hundred alternations of freezing and thawing somewhat decreased the strengths. Freezing and thawing combined with drying and soaking affected some of the concretes and mortars so as to cause spalling after about 100 freezings and thawings and about 30 dryings at 65° C. (150° F.) to such an extent that the concrete was no longer serviceable.

Mortars and concretes containing the same ratio of cement to water were approximately equal in strength at early ages. At later ages the mortar specimens tended to give higher strengths than the concrete.

The heat evolved by the cements was measured by storing concrete cylinders made from them in an adiabatic calorimeter, i.e., an instrument which did not allow any of the heat to escape. The rise in temperature of the concrete was used as a basis for calculation of the heat evolved, which varied from 104 to 130 cal. per g. of cement, after 90 days' storage in the calorimeter.

A more complete description of this work will be published as RP799 in the June number of the *Journal of Research.*

THERMAL SPALLING OF FIRE-CLAY BRICK.

A discussion of the probable relation between linear thermal expansion, modulus of rupture, modulus of elasticity, and the resistance of fire-clay brick to thermal spalling is presented in a current issue of the *Bulletin of the American Refractories Institute.*

Because of the readiness with which the linear thermal expansion of the usual type of fire-clay brick decreases, or in the case of the siliceous type of brick increases, when heated at a temperature higher than reached during the manufacturing process, and also because of the temperature gradient in bricks in furnace walls which are being heated or cooled, large stresses may be set up in the bricks. Unless the bricks in which such stresses are set up have the necessary extensibility or, expressed differently, the ability to "stretch" a suitable amount to permit adjustment of the various sections of the brick to those stresses, rupture will take place. The extensibility of the refractory brick or shape is decreased as a rule (*a*) by increasing the temperature of firing during manufacture, (*b*) by using comparatively fine grog sizes in their composition, and (*c*) by decreasing the amount of grog. Refractory shapes apparently show less resistance to thermal shock if they contain vitreous grog rather than porous. Furthermore, of two brands of bricks which have approximately the same properties at room temperature, that brand showing the greatest decrease in extensibility between room temperature and 600° C. (1,112° F.) will have the lower resistance to thermal shock.

Values for Young's modulus of elasticity are compared for individual units of the same brand of bricks as well as of specimens cut from different parts of the same unit to show the uniformity of the product. A comparison of the values of the elasticity obtained on two units each of three brands of bricks showed the difference between the two units to range from about zero to 72 per cent. However, when comparing the values obtained on six specimens from one

brick, the modulus of elasticity may vary more than 180 per cent.

ADVISORY COMMITTEE ON REFRACTORIES.

There has been organized recently an Industrial Advisory Committee on Refractories to the National Bureau of Standards. The committee representatives were appointed from eight companies manufacturing refractories and one from the Refractories Fellowship at Mellon Institute. The function of this committee is twofold, namely: (1) to keep the members of the refractories industry in close contact with current research studies and testing work on refractories, and (2) to suggest and discuss problems for future research dealing with refractory materials.

The first meeting of this committee was held at the Bureau on April 24th and those attending were: C. E. Bales, Ironton Fire Brick Company, Ironton, Ohio; R. S. Bradley, A. P. Green Fire Brick Company, Mexico, Mo.; F. A. Harvey, Harbison-Walker Refractories Company, Pittsburgh, Pa.; J. M. McKinley, North American Refractories Company, Cleveland, Ohio; S. M. Phelps, American Refractories Institute, Pittsburgh, Pa.; L. J. Trostel, General Refractories Company, Baltimore, Md.; and P. H. Bates and R. A. Heindl, National Bureau of Standards, Washington, D. C.

During the morning session the organization of the Bureau, its relation to the Government Departments, its contacts with the producing and consuming public and the funds available for research on refractory materials were explained in considerable detail by P. H. Bates, chief of the division of clay and silicate products. The committee raised objections to certain tests made in connection with the routine testing of refractory materials.

In the afternoon session the various activities of the refractories section of the Bureau were briefly described and the current investigations with the results obtained were given in some detail by the several workers engaged in the studies.

ALLOYS FOR BASIC TYPES OF INGOT METALS.

The Non-Ferrous Ingot Metal Institute is supporting at the Bureau, under the research-associate plan, studies of the

various alloys which may be considered as basic types for the industry.

A study has just been completed on the physical properties of red brass containing 82 per cent. copper, 3 per cent. tin, 5 per cent. lead, and 10 per cent. zinc. This alloy is considered to be on the low-copper side of the group of alloys classed by the American Society for Testing Materials as red brasses and for which the NRA Code Authority has accepted as the basic alloy, the composition consisting of 85 per cent. copper and 5 per cent. each of tin, lead, and zinc. The comparison of the physical properties of the modified alloy and the basic alloy, cast under comparable conditions, indicates the modified alloy to be superior in ductility, fluidity, and electrical conductivity, but slightly inferior in yield point and hardness, the differences in tensile strength and density being very small.

STEEL PRINTING PLATES.

The Bureau is engaged in a study of work-hardening and the aging characteristics of low-carbon and medium-carbon steel plates such as are used in the mechanical transfer process of producing engraved printing plates. This work is being done in coöperation with the Bureau of Engraving and Printing of the Treasury Department. Both open-hearth and Bessemer steels are included in the studies. The several steels are subjected to various degrees of cold-rolling representative of the cold working received in the actual mechanical transfer process used in producing printing plates, and their mechanical properties are then determined. The modifications in properties resulting from cold work and aging are believed to be important factors determining that rather indefinite characteristic of carbon steel plates which the transfer press operators call "transfer quality."

ETCHING STAINLESS STEELS.

All metals are composed of small imperfect crystals known as grains. The size, shape, and structure of these grains are of great importance to the metallurgist in his study of any metal and its application in service. Satisfactory revealing of grain structures is usually accomplished by

etching with some suitable chemical reagent, with or without the application of an electric current. These structures may then be studied under the metallurgical microscope at suitable magnifications.

Certain of the metals are difficult to etch satisfactorily because of composition. This is particularly true of stainless steels, because they resist attack by the ordinary reagents. Generally, it has been necessary to use strong mixed acids to reveal the structures, thus necessitating great care in handling and disposal after use.

A new method recently used at the Bureau in a study of the changes induced in stainless steels upon welding promises to be far superior to all others. This consists in etching electrolytically in oxalic acid (10 grams dissolved in 100 milliliters of water), the specimen being the anode and a piece of platinum the cathode. Current is supplied from 4 dry cells in series or from a 6-volt storage battery. Carbides are revealed in from 15–30 seconds' etching time, and an addition 30–45 seconds will reveal also the grain boundaries in the 18–8 (18 per cent. Cr, 8 per cent. Ni) type. The solution is relatively rapid in etching action and does not stain the specimen, a drawback of almost all other methods.

SEPARATION OF THE SIX PLATINUM METALS FROM ONE ANOTHER AND THEIR GRAVIMETRIC DETERMINATION.

At the meeting of the division of physical and inorganic chemistry of the American Chemical Society in New York on April 25, a paper on the separation of the platinum metals and their gravimetric determination was presented by Dr. Raleigh Gilchrist. The following is an abstract of this paper:

A detailed procedure has been developed at the Bureau by which the six platinum metals can be quantitatively separated from one another and determined gravimetrically.

In this system of analysis, precipitation with ammonium chloride, fusion with pyrosulphate and extraction of metallic mixtures with acids, are avoided entirely. Other departures from the usual procedures are as follows: Collecting osmium in hydrochloric acid containing sulphur dioxide, instead of in an alkaline solution; distilling ruthenium from an acid solution,

in the presence of sodium bromate, and collecting it in hydrochloric acid containing sulphur dioxide; determining osmium and also ruthenium by precipitating their respective hydroxides from solutions originally acid; separating platinum from palladium, rhodium, and iridium, by precipitating the hydroxides of the three last-named metals under conditions of controlled hydrolysis; separating rhodium from iridium by reducing the former metal with titanous chloride, together with a technic for preparing the precipitated metallic rhodium for the necessary reprecipitation; determining iridium by precipitation and direct ignition of its hydroxide.

The reagents employed are generally available, and no unusual equipment is required. While the operations must be performed carefully, they do not involve technic unfamiliar to a trained analyst.

The six platinum metals are separated from one another in the following order: Osmium, ruthenium, platinum, palladium, rhodium, iridium.

(*a*) *Separation and Determination of Osmium.*—Osmium is removed first by forming its tetroxide in a solution of the six platinum metals containing 10 per cent. of nitric acid by volume. The apparatus used consists of a 700-ml. distilling flask, a set of three 300-ml. absorbing flasks, and a train of inlet and delivery tubes which are sealed into one piece. The flasks are attached to the apparatus by means of ground joints. The tetroxide is swept from the boiling solution by a gentle current of air and absorbed in 6 normal hydrochloric acid saturated with sulphur dioxide. The absorbent solutions are combined and evaporated to a sirup on the steam bath. The sirupy residue is digested with concentrated hydrochloric acid and evaporated. This operation is repeated several times to ensure complete decomposition of sulphite compounds of osmium. The osmium solution is finally diluted to 150 ml., heated to boiling, and its acidity reduced by the addition of sodium bicarbonate until a value of pH 4 is reached, as indicated by bromphenol blue. The solution is boiled for 5 to 6 minutes to ensure complete precipitation. The hydrated dioxide of osmium is caught on a Munroe platinum crucible, washed well with a hot 1 per cent. solution of ammonium chloride, impregnated with saturated ammon-

ium chloride, dried by suction, and ignited to metal under hydrogen. The hydrogen atmosphere is finally displaced with carbon dioxide. The residue is weighed as metallic osmium.

(*b*) *Separation and Determination of Ruthenium.*—The solution in the distilling flask, after the removal of osmium, is evaporated on the steam bath to eliminate nitric acid. It is then evaporated several times with concentrated hydrochloric acid to expel oxides of nitrogen. The resulting solution is diluted somewhat, 10 ml. of concentrated sulphuric acid is added, and this solution heated until vapors of sulphuric acid are evolved. The sulphate solution, together with any metallic platinum, is returned to the distilling flask and diluted to about 100 ml. Ruthenium as tetroxide is eliminated from the boiling solution by the addition of sodium bromate. The tetroxide is absorbed in hydrochloric acid saturated with sulphur dioxide, in the same manner and in the same apparatus that was used for osmium. The ruthenium is recovered from the evaporated absorbent solution in a manner similar to that used for recovering osmium, except that the precipitation is made at pH 6, using brocresol purple indicator. The precipitate is caught on filter paper, washed with a hot 1 per cent. solution of ammonium sulphate, then with a cold 2.5 per cent. solution of the same reagent, ignited to an anhydrous oxide, reduced in hydrogen, and finally weighed as metallic ruthenium.

(*c*) *Separation and Determination of Platinum.*—The simplest and most direct way to separate platinum from palladium, rhodium, and iridium, is to precipitate collectively by hydrolysis the hydrated oxides of palladium, rhodium, and iridium.

The solution in the distilling flask, after the elimination of ruthenium, is prepared for the precipitation of palladium, rhodium, and iridium. The hydrated oxides of these three metals are completely precipitated by hydrolysis at pH 6 in a boiling solution containing sodium bromate. In order to ensure the complete elimination of platinum, the precipitate of hydrated oxides is dissolved in hydrochloric acid and the above precipitation repeated.

The platinum is recovered by hydrogen from the filtrates of the above precipitations, after destruction of residual bromate. In extremely careful work, the ignited sulphide is redissolved and the platinum again precipitated, this time by formic acid in a solution buffered with sodium acetate. The precipitated metal is ignited and weighed as metallic platinum.

(*d*) *Separation and Determination of Palladium.*—Palladium is separated from a solution of the hydrolytic precipitate of palladium, rhodium, and iridium in hydrochloric acid, by means of dimethylglyoxime. A single precipitation appears to effect a clean separation of palladium from rhodium and iridium. The palladium is determined either as the flyoxime compound, using the theoretical factor, 0.3167, or as metal. When determined as metal, the glyoxime precipitate is caught on paper, ignited in air, reduced in hydrogen, ignited in carbon dioxide and cooled in this gas.

(*e*) *Separation and Determination of Rhodium.*—The filtrate from the precipitation of palladium is evaporated with 10 ml. of sulphuric acid. Organic matter is destroyed by the addition of nitric acid. The solution is heated to vapors of sulphuric acid in order to convert the two metals to sulphates. The solution is diluted to 200 ml., heated to boiling, and the rhodium precipitated as metal by adding titanous chloride in slight excess. The precipitated metal is dissolved in boiling sulphuric acid and the precipitation repeated to ensure complete removal of iridium. The metallic rhodium is again dissolved in sulphuric acid, and the resulting solution converted to a rose-colored solution by heating with hydrochloric acid. The rhodium is recovered by hydrogen sulphide, ignited in air, reduced in hydrogen, and weighed as metallic rhodium.

(*f*) *Recovery and Determination of Iridium.*—Iridium is recovered from the filtrates of the titanous chloride precipitations of rhodium, by hydrolytic precipitation at pH 6 in the presence of bromate, after the removal of titanium by cupferron. It is weighed as metallic iridium.

An alternative procedure for the determination of iridium consists in determining rhodium and iridium together as a metallic mixture in an aliquot portion of the solution containing these two metals. In this way, the cupferron pre-

cipitations are avoided. Rhodium must be determined independently in another aliquot portion in the manner outlined above.

In the development of the foregoing procedure, it was found that under the conditions established for distilling osmium tetroxide, and also for distilling ruthenium tetroxide, none of the other platinum metals, except the one being distilled, appeared in the absorbing solution. In the separation of platinum, palladium, rhodium, and iridium from one another, each of these metals was isolated without significant contamination by the other three metals. The errors observed in the determination of the recovered metals ranged from -0.2 to $+0.2$ mg., and averaged within 0.1 mg. of the quantities taken, which, in the experimental work, varied from 100 to 300 milligrams.

SWEET POTATO STARCH FOR THE BEATER SIZING OF PAPER

Referring to an item on this subject in Technical News Bulletin no. 211 (November 1934), the Bureau is now definitely of the opinion that an excellent starch for sizing printing papers can be made from cull sweet potatoes. This conclusion is based on the results of recent experiments at the Bureau, on starch produced by scientists at the U. S. Department of Agriculture. The profitable utilization of at least a part of this farm waste in the domestic paper industry would mean increased income for the farmer.

Corn and cassava starches, the latter an imported product, are widely used as beater sizings in book and catalog papers to improve printing quality. The suitability of the sweet potato product for this purpose was appraised by making, in the Bureau's experimental paper mill, a series of book papers in which the sweet potato starch was used in comparison with representative commercial sizing starches made from corn and cassava. The results obtained with sweet potato starch were equal to the best results obtained with the other starches with respect to strength and opacity of the papers, and superior with respect to retention of mineral filler, and "closing the sheet," as indicated by air permeability. Hence, the starch from cull sweet potatoes is apparently a high grade

material for beater sizing, at least equal in quality to the best commercial starches commonly used for the purpose.

STANDARD TIME THROUGHOUT THE WORLD.

The rapid development of modern means of national and international communication has brought about a greater realization of the difference in time between different geographic centers. To answer the many demands for information on standard time, the Bureau several years ago published a pamphlet entitled "Standard Time Throughout the World," the latest revision of which has just been issued under the designation Circular C406. This circular gives a brief historical sketch of the development of the standard time system, time zone maps of the United States and of the World, a list of stations transmitting radio time signals, a list of the times used in several large cities, a list of the legal times used in most of the countries of the world, and other information regarding standard time.

Copies of this publication are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

Electroplating Worn Iron Parts.—(*Elec. Jnl.*, Vol. 32, No. 6.) The process of electrodeposition of iron, although entirely practical commercially, is not extensively used for repairing worn or undersized parts by depositing iron on them in an electroplating bath. One large organization, however, has used it successfully on 70 or 80 salvage jobs. The exact chemicals to use can vary. A successful solution consists of 300 grams of the crystallized ferrous ammonium sulphate per liter and worked at 50 to 70° C. Anodes can be made of 0.036 inch Armco iron formed into cylinders 5 in. long and 8 in. in diameter with a disc of 1/8 inch insulating material at each end of the anode, and with a 2 in. hole in the center to permit a motor driven stirring rod to be inserted. The tendency for oxidation can be greatly retarded by the addition of a "mud" ferrous carbonate. Current densities of 6 to 7 amperes per square decimeter may be satisfactory. Hot solutions constantly stirred with high current densities produce deposits more rapidly, at higher efficiency, and a better quality deposit. Parts should be roughly cleaned and made the cathode in a solution of about 5 per cent. caustic soda and 5 per cent. sodium carbonate, then they should be given an anodic treatment in approximately 30 per cent. sulphuric acid with enough current density to induce passivity. After rinsing they can be transferred to the plating bath. This anodic process is the only one that will give adherent deposits.

R. H. O.

Tungsten Versus Chromium Plating.—(*Metal Cleaning and Finishing*, May, 1935.) In discussing tungsten plating, W. A. KOEHLER of West Virginia University points out that this metal is in the same series as chromium in the periodic system. It has a bright silvery luster, but unlike chromium, it is not attacked by any of the common mineral acids, but can be dissolved by a mixture of nitric and hydrofluoric acids. A thick coating of metallic tungsten can be plated electrolytically and is especially valuable for covering baser metals in laboratory ware. The metal is not affected by sulfur or phosphorus. It has a hardness on Mohr's scale of about seven.

The tungsten plating solution is easy to prepare. A saturated solution of sodium carbonate is made at 100° C. and tungsten trioxide, WO_3 is added as long as the sodium tungstate formed is soluble. The solution is electrolyzed usually at 75 amperes per sq. ft. and the higher the temperature, the brighter the deposit. The solution is not entirely stable and will slowly deteriorate when used constantly.

C.

THE FRANKLIN INSTITUTE

INCOME AND EXPENSES FOR EIGHT MONTHS ENDED MAY 31, 1935.

This financial statement for the first eight months of the fiscal year is published for the information of the members and friends of the Institute. The deficit shown, amounting to $300.00 per day, has not changed materially since the opening of the Museum.

Income.

Dues			$13,116.00
General Funds			89,958.88
Admissions—			
Museum	$36,230.80		
Planetarium	18,798.10		
Museum Sales	2,905.57		57,934.47
Publications			5,819.04
Miscellaneous			4,492.75
Total Income			$171,321.14

Expenses.

	Salaries and Wages.	*Other Expenses.*	*Total.*	
Operating—				
Building	$ 30,358.17	$29,511.10	$59,869.27	
Library	10,529.44	4,526.59	15,056.03	
Meetings	—o—	3,404.87	3,404.87	
Office and General	30,186.81	8,663.29	38,850.10	
Museum	71,320.71	21,544.52	92,865.23	
Publications	—o—	8,909.15	8,909.15	
Science and the Arts	2,437.36	177.22	2,614.58	
Miscellaneous	83.36	759.00	842.36	
	$144,915.85	$77,495.74		
Total Operating Expenses				222,411.59
Total Operating Deficit				51,090.45
Capital Expenditures for Equipment				10,166.54
Total Deficit				$ 61,256.99

The Finance Committee,

WALTON FORSTALL, MARSHALL S. MORGAN,
BENJAMIN FRANKLIN, JAMES S. ROGERS.
O. J. MATTHEWS,

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, June 12, 1935.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JUNE 12, 1935.

MR. CHARLES H. MASLAND, 2ND, *in the Chair.*

The following reports were presented for first reading:

No. 2976: High Voltage Generator.
No. 2993: Sprayed Metal Coating Process.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

RESIDENT.

MR. HARRY L. ACOMB, Treasurer and Technical Director, Kemide Manufacturing Company Inc., Port Kennedy, Pa.

MR. LAWRENCE J. FULLER, Development Engineer, Dellenberger Machine Company, Philadelphia, Pa. For mailing: 232 East Meade Street, Chestnut Hill, Pa.

MR. JOHN F. HAMMOND, Chemistry Teacher, Villanova College, Villanova, Pa.

MISS MARY ALLISON REED, Staff Member, Academy of Natural Sciences, Philadelphia, Pa. For mailing: Wyncote, Pa.

MR. WILLARD T. SHOENER, Research Work, P. Blakiston Son and Company, Philadelphia, Pa. For mailing: 36 School Street, Ambler, Pa.

NON-RESIDENT.

MR. A. I. APPELBAUM, Chemist, International Products Corporation, Trenton, New Jersey. For mailing: 333 Ardmore Avenue, Trenton, New Jersey.

MR. MYRON P. LAUGHLIN, Patent Lawyer, General Motors Corporation, Detroit, Michigan.

STUDENT.

MR. ALBERT FISCH, JR., 2837 Ruth Street, Philadelphia, Pa.

MR. JOHN D. GILL, JR., 307 Bryn Mawr Avenue, Bala-Cynwyd, Pa.

MR. BRIGGS H. NAPIER, 605 Glenwood Avenue, East Lansdowne, Pa.

MUSEUM MEMBERSHIP.

INDIVIDUAL.

MR. GARABAD HOVNANIAN, 6733 Emlen Street, Philadelphia, Pa.

MR. WILLIAM H. KATZ, 1310 Spruce Street, Philadelphia, Pa.

MR. CARL R. PASSEHL, 4717 North Thirteenth Street, Philadelphia, Pa.

STUDENT.

MR. ROBERT S. SCHREIBMAN, 5344 Lebanon Avenue, Philadelphia, Pa.

MR. STANLEY WAND, 933 Linden Street, Camden, New Jersey.

CHANGES OF ADDRESS.

LIEUT. COMMANDER F. W. BELTZ, c/o District Supervisor, Alcohol Tax Unit, Standard Bank Building, Cleveland, Ohio.
MR. CHARLES C. BRUSH, 40 Chase Street, South Portland, Maine.
MR. EDWIN BURHORN, Wynetta, Arkville, Delaware County, New York.
MR. F. L. DUBOSQUE, 51 Bayview Avenue, Great Neck, New York.
MR. GANO DUNN, 550 Park Avenue, New York City, New York.
PROF. A. S. EVE, c/o Bank of Montreal, 9 Waterloo Place, London, S. W. 1, England.
MR. ERWIN D. A. FRANK, Apt. No. 2, 1943 North Summitt Avenue, Milwaukee, Wisconsin.
MR. FRED B. KAUFMAN, Hotel Detroiter, Woodward at Adelaide, Detroit, Michigan.
MR. CHARLES H. NORDHAUS, 4513 North Lincoln Street, Chicago, Illinois.
MR. THOMAS M. RECTOR, R.F.D. No. 2, Morristown, New Jersey.
REAR ADMIRAL W. S. SIMS, U.S.N., Marion, Massachusetts.
MR. ALLEN C. STALEY, 711 Albey Road, Birmingham, Michigan.
MR. R. J. WENSLEY, Moylan, Pennsylvania.

NECROLOGY.

Mr. J. M. Rusby, Philadelphia, Pa.

LIBRARY NOTES.

RECENT ADDITIONS.

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BOOK REVIEWS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 510, Wind-Tunnel Research Comparing Lateral Control Devices Particularly at High Angles of Attack. XIII—Auxiliary Airfoils Used as External Ailerons, by Fred E. Weick and Richard W. Noyes. 32 pages, tables, illustrations, 23.5 × 29 cms. Washington, Superintendent of Documents, 1935. Price ten cents.

This is the thirteenth report on a series of systematic tests comparing lateral control devices with particular reference to their effectiveness at high angles of attack. The present tests, conducted in the N.A.C.A. 7- by 10-foot wind tunnel, were made to determine the most feasible locations for lateral control surfaces mounted externally to a rectangular Clark Y wing.

Two sets of external ailerons were used. One had an N.A.C.A. 0012 symmetrical profile and a chord length that was 15 per cent. of the main wing chord. The other set of ailerons, which was used at only a few test positions, had an N.A.C.A. 22 cambered profile and a chord length of 14.5 per cent. of the main wing chord. Both ailerons extended over the full span of the main wing and were hinged about an axis on their chord line 20 per cent. from their leading edge. The range of positions investigated was from 27 per cent. of the main wing chord ahead of the leading edge of the main wing to 10 per cent. behind the trailing edge and from 40 per cent. above the chord to 20 per cent. below the chord.

The results of the wind-tunnel tests showed that no location tested for external ailerons was entirely satisfactory with respect to both performance and control. The best locations tested lay in a region between the leading edge and 30 per cent. of the chord back from the leading edge, and from 3 to 9 per cent. above the upper surface. Choice of a particular location depends on a compromise between good performance, obtainable near the leading edge, and good control, obtainable near the rear of the favorable region.

Flight tests made with external ailerons in one of the positions over the forward part of the wing showed serious practical difficulties due to heavy hinge moments and irregular control-force variation.

Report No. 511, The Effect of Baffles on the Temperature Distribution and Heat-Transfer Coefficients of Finned Cylinders, by Oscar W. Schey and Vern G. Rollin, 13 pages, illustrations, 23.5 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

An investigation was made to determine the effect of baffles on the temperature distribution and the heat-transfer coefficient of finned cylinders. The tests were conducted in a 30-inch wind tunnel on electrically heated cylinders with fins of 0.25- and 0.31-inch pitch.

Four types of baffles were tested: Plates mounted at various positions around the cylinder and at various angles with respect to the air stream; streamline baffles mounted near the rear of the cylinder; shell baffles with variously shaped openings mounted around the test cylinder symmetrically with respect to a plane through the axis of the cylinder and parallel to the air stream; and integral baffles composed of strips welded to the tips of the fins of the test cylinder to form passages between the fins through which the air could flow to the rear of the cylinder.

The results of these tests showed that the use of integral baffles gave a reduction of 31.9 per cent. in the rear-wall temperatures and an increase of 54.2 per cent. in the heat-transfer coefficient as compared with a cylinder without baffles.

Although the effects of the shell baffles were not equal to those of the integral baffles, they gave a large reduction in rear-wall temperatures and a large increase in the heat-transfer coefficient. The best results were obtained with the shell baffles mounted in contact with the fins, when the intake opening was equal to the arc subtended by an angle of approximately 145°, when the extensions were 3 inches or more in length, and when the ratio of exit area to area between fins was approximately 1.6. The heat-transfer coefficient with the best shell baffles varied as the air speed to the 0.85 power.

Report No. 512, Some Factors Affecting Combustion in an Internal-Combustion Engine, by A. M. Rothrock and Mildred Cohn. 17 pages, illustrations, 23.5 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

An investigation of the combustion of gasoline, safety, and diesel fuels was made in the N.A.C.A. combustion apparatus under conditions of temperature that permitted ignition by spark with direct fuel injection, in spite of the compression ratio of 12.7 employed. The influence of such variables as injection advance angle, jacket temperature, engine speed, and spark position was studied. The most pronounced effect was that an increase in the injection advance angle (beyond a certain minimum value) caused a decrease in the extent and rate of combustion. In almost all cases, combustion improved with increased temperature. For an increase in engine speed, the rate of pressure rise increased and the time interval in seconds between injection and the spark necessary to effect ignition was considerably shortened. Although all three fuels reacted in the same manner to these variable conditions, the reactions differed decidedly in extent. The results show that at low air temperatures the rates of combustion vary with the volatility of the fuel, but that at high temperatures this relationship does not exist and the rates depend to a greater extent on the chemical nature of the fuel.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Report No. 514, The Measurement of the Field of View from Airplane Cockpits, by Melvin N. Gough, 12 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1935. Price ten cents.

A method has been devised for the angular measurement and graphic portrayal of the view obtained from the pilot's cockpit of an airplane. The assumptions upon which the method is based and a description of the instrument, designated a "visiometer," used in the measurements are given. Account is taken of the fact that the pilot has 2 eyes and thus 2 separate sources of vision. The view is represented on charts using an equal-area polar projection, a description and proof of which are given. The use of this chart, aside from its simplicity, may make possible the establishment of simple criterions of the field of view. Charts of five representative airplanes with various cockpit arrangements are included.

Report No. 515, Full-Scale Wind-Tunnel Tests of a PCA–2 Autogiro Rotor, by John B. Wheatley and Manley J. Hood, 10 pages, tables, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1935. Price five cents.

This paper presents the results of force tests on and air-flow surveys near a PCA–2 autogiro rotor in the N.A.C.A. full-scale wind tunnel. The force tests were made at three pitch settings and several rotor speeds; the effect of fairing protuberances on the rotor blade was determined. Induced downwash and yaw angles were determined at two tip-speed ratios in a plane 1½ feet above the path of the blade tips. The results show that the maximum L/D of the rotor cannot be appreciably increased by increasing the blade pitch angle above about 4.5° at the blade tip; that the protuberances on the blades cause more than 5 per cent. of the total rotor drag; and that the rotor center-of-pressure travel is very small.

Report No. 516, Potential Flow About Elongated Bodies of Revolution, by Carl Kaplan. 20 pages, tables, 23.5 × 29 cms. Washington, Superintendent of Documents, 1935. Price ten cents.

This report presents a method of solving the problem of axial and transverse potential flows around arbitrary elongated bodies of revolution. The solutions of Laplace's equation for the velocity potentials of the axial and transverse flows, the system of coördinates being an elliptic one in a meridian plane, are known to be of the following form:

$$\varphi = \sum_{n=1}^{\infty} A_n Q_n(\lambda) P_n(\mu) \text{ (axial flow)},$$

$$\varphi = \sum_{n=1}^{\infty} A_{n1} Q_n^1(\lambda) P_n^1(\mu) \cos\theta \text{ (transverse flow)}.$$

If a power-series development of λ in μ is assumed as the equation of the meridian profile in elliptic coördinates, the boundary conditions of the two types of flow yield linear equations for the determination of the coefficients A_n and A_{n1}. It is further shown that a knowledge of these coefficients leads directly to the sink-source and doublet distributions corresponding to the axial and transverse flows, respectively.

The theory is applied to a body of revolution obtained from a symmetrical Joukowsky profile, a shape resembling an airship hull. The pressure distribution and the transverse-force distribution are calculated and serve as examples of the procedure to be followed in the case of an actual airship. A section on the determination of inertia coefficients is also included in which the validity of some earlier work is questioned.

Report No. 517, Flight Investigation of Lateral Control Devices for Use with Full-Span Flaps, by H. A. Soulé and W. H. McAvoy. 11 pages, illustrations, 23.5 × 29 cms. Washington, Superintendent of Documents, 1935. Price ten cents.

Flight tests were made of five different lateral control devices that appeared adaptable to wings fitted with full-span flaps: Controllable auxiliary airfoils (airfoils mounted above and forward of the leading edge of the wings), external ailerons (airfoils mounted above the wing and slightly forward of its maximum ordinate), upper-surface ailerons (similar to split trailing-edge flaps except that they constitute the upper surface of the wing), ailerons that retract into the wing when in neutral, and narrow-chord conventional ailerons in combination with a special type of split flap that retracts into the under surface of the wing forward of the ailerons. The devices were tested on a small parasol monoplane.

Only the retractable ailerons and the narrow-chord ailerons in combination with the special split flap were found to be satisfactory. The absence of appreciable aerodynamic hinge moments of the retractable ailerons was considered to be somewhat objectionable but this characteristic can probably be remedied by a slight modification. The external ailerons were unsatisfactory in the normal-flight range because of an irregular variation of their hinge moments with deflection and a relatively weak rolling action. These ailerons are believed to warrant further development, however, because they retain their effectiveness above the stall. The controllable auxiliary airfoils had lag as well as excessive hinge moments and hence appear to warrant no further development. The upper-surface ailerons had excessive hinge moments but were otherwise satisfactory.

Experience gained in the use of flaps during these tests has indicated the desirability of a flap that can be operated quickly and easily.

R.

THE FRONTIERS OF PSYCHOLOGY, by William McDougall, M.B., F.R.S. 235 pages, 13 × 20 cms. New York, D. Appleton-Century Company, Inc. Cambridge, University Press, n.d. Price $2.00.

Psychology as a science is of comparatively recent origin. Its growth and progress, however, has been rapid but not without the dangers, not always successfully avoided, of faulty methods of obtaining data, insufficient data, and hasty interpretation of data. The progress of science in general has reached the point where there are found unexplored regions that lie between recognized boundaries of provinces of subjects. In these regions lie many problems which may be solved only by coöperation of two or more sciences. This book treats on leading examples of those typical frontier problems, as they are called. It demonstrates that since every science is a product of mental activity, the workers in each

science come up against psychological problems, questions as to the ways of the working of the human mind, as to its liabilities to error, to bias and consequent distortion, to selection, etc., as to the influence of all such peculiarities in shaping the conceptions and theories of each science. It discusses the frontier toward the abstract and physical sciences, energy and force, history and psychology, and the nature of value. A feature of the book is the criticism of the naive psychology of Jeans, Eddington and Einstein in their more mystical speculations regarding the structure and control of the universe.

The book is one of a series known as the Contemporary Library of Psychology which has been drawn up with a view to presenting a comprehensive and accurate perspective of contemporary psychology in a popular way without losing scientific accuracy.

It is a book for serious general readers. Its treatment is simple, clear cut, consistent, mature and emphatic. Workers in all sciences whose frontiers are bounded by psychological problems should be interested.

R. H. OPPERMANN.

LEXIQUE TECHNIQUE ANGLAIS-FRANCAIS, par Guy Malgorn, avec la collaboration de M. Desmarets. 254 pages, 14 × 22 cms. Paris, Gauthier-Villars, 1934. Price 25 francs.

This is a revised and corrected second edition of the English-French technical dictionary, by Guy Malgorn. The vocabulary applies principally to various types of machine tools, the elements of the internal combustion engine, aviation, electricity, radio broadcasting and communication, naval construction, metallurgy and so forth. The front of the volume contains a number of conversion tables often of great convenience to technical men.

T. K. CLEVELAND.

ELECTROCHEMISTRY, PRINCIPLES AND PRACTICE, by C. J. Brockman, Associate Professor of Chemistry, University of Georgia. 348 pages, tables, 15 × 23 cms. New York, D. Van Nostrand Company, Inc. Price $4.00.

This work represents a very worthy addition to the series of Industrial Chemical Monographs. Electrochemistry may not be still in its infancy but neither has it yet attained the stage of its fullest development. The author has undertaken to present his subject in a not too technical manner. As such, this book will appeal not only to the chemist but to the plant manager, manufacturer and executive as well. All types of chemical processes involving the use of electricity are described entertainingly and the extensive treatment of the subject makes the book a valuable addition to any chemical or general technical library.

The author begins with a chapter on the Principles of Electrochemistry. This is logically followed by a description of oxidation reactions at the anode and reduction reactions at the cathode. The electrometallurgy of metals comprises a large section of the book and well it might, for such processes of metal winning and refining furnish the basis for many large modern plants. A study of the manufacture of bleaching agents is essentially a course in electrochemistry. The present-day low prices for such metals as aluminum, magnesium, sodium, calcium, cerium, and beryllium owe their existence to improved electrochemical technique. In many instances it is not the conductivity of substances that is

important, but rather their resistivity. This resistance to electrical flow results in the production of heat which in turn drives on the reaction, such as in the production of carbide, carborundum, graphite and corundum. In other processes heat may be applied without involving the direct application of the electric current such as in the arc, induction and resistor furnaces.

T. K. CLEVELAND.

ELEMENTS OF STRENGTH OF MATERIALS, by S. Timoshenko, and Gleason H. MacCullough, 350 pages, illustrations, 15.5 × 23.5 cms. New York, D. Van Nostrand Company, Inc., 1935. Price $3.25.

A newer and abridged edition of Timoshenko's "Strength of Materials" which is designed as a text for undergraduate courses in American schools of engineering. The book gives a vigorous and efficient treatment of the subject in a well designed layout. The student is started off with a part dealing with tension and compression following which is a part on combined stresses. The third chapter on joints and stresses in thin walled cylinders contains treatment particularly illustrative of the briefness and conciseness of the book in its entirety. Torsion, bending, strains and stresses are all taken up, together with practical applications of theory to beams, columns, etc., to complete the subject. Both the double integration and area-moment methods for solving problems in deflection of beams are presented so that either may be used independently. The problem of reinforced concrete beams, in accord with some recent textbooks, no longer depends on formulas for solution but rather utilizes the simplest of fundamental principles in its solution.

Throughout the book extensive use is made of problems and their solution. About half of those given are answered, the others are along the same general lines. All of the problems are cleverly selected to emphasize the point to be brought out. The authors recommend the use of a structural steel handbook in conjunction with this text but they state that it is not absolutely necessary for abridged tables of elements of sections of such structural shapes, needed in the solution of the problems, are included in the Appendix. A subject index is also appended.

The serious minded student who is qualified to absorb this material should benefit greatly in using this book as a text. Its brevity, directness of treatment, and completeness cannot be overstated. The practicing engineer should find in this book much of value, aside from its being illustrative of a modern text on the subject. It is especially, easy to refer to and for use in reviewing or refreshing one's memory on the various topics treated.

R. H. OPPERMANN.

THE RISE OF MODERN PHYSICS, by Henry Crew, Professor Emeritus of Physics in Northwestern University, second edition. 434 pages, diagrams, 13 × 19 cms. Baltimore, The Williams & Wilkins Company, 1935. Price $4.00.

The first edition of this book met with very popular response to the extent that after five years from the date of publication it was exhausted. There followed a period of three years before this second edition was published during which time it was possible for the author to mould an additional three chapters dealing with three groups of phenomena that have only lately been reduced to order.

In the Preface the author explains his distinction between the words "modern"

and "recent" as applied to the title of the book. The word "modern" is used in the same sense in which historians usually employ it; namely, to cover the period subsequent to the renaissance. In science this is since the time of Galileo or roughly the last three centuries of completed subjects. The book is limited to including very little on what is being put together today.

Beginning with Chapter I, the introduction, the reader is given an outline of basic treatment upon which the rest of the book is constructed. It is a brief summary of four chapters of science of the ancients from 3000 B.C. or thereabouts when it was observed that copper could be extracted from its ore by a hot fire, to about the year 1632. Following this it treats in a more detailed manner the history of modern physics. The book then is divided conveniently into parts which are discussed by themselves with easier understanding. For example chapters are devoted to the foundation of modern optics, pioneers in electricity and magnetism, from Volta to Oersted, the rise of modern spectroscopy, the origin of modern electrical units, etc. Each of these chapters embody a distinct coverage so that when they are linked together to form the book the result is a comprehensive account.

Aside from the excellent construction and the extensive factual data contained in the book, the author has a style of writing that renders the book extremely interesting and inspiring. It certainly is not difficult to read even for the non-technical reader and the impressions gained are sure to be lasting.

A brief bibliography by authors is appended as well as a very useful index.

R. H. OPPERMANN

PUBLICATIONS RECEIVED.

The Rise of Modern Physics, by Henry Crew, 434 pages, illustrations, 13 × 19 cms. Baltimore, The Williams & Wilkins Company, 1935. Price $4.00.

Mathematics and the Question of Cosmic Mind, with Other Essays, by Cassius Jackson Keyser, 121 pages, 13 × 19.5 cms. New York, Scripta Mathematica, 1935.

Elements of Strength of Materials, by S. Timoshenko and Gleason H. MacCullough, 350 pages, illustrations, 15.5 × 23.5 cms. New York, D. Van Nostrand Comapny, Inc., 1935. Price $3.25.

An Introduction to Astronomy, by Robert H. Baker, 312 pages, illustrations, tables, 15.5 × 24 cms. New York, D. Van Nostrand Comapny, Inc., 1935. Price $3.00.

U. S. Bureau of Mines, Technical Paper 562, Carbonizing Properties and Constitution of Alma Bed Coal from Spruce River No. 4 Mine, Boon County, W. Va., by A. C. Fieldner, J. D. Davis, R. Thiessen, E. B. Kester, W. A. Selvig, D. A. Reynolds, F. W. Jung and G. C. Sprunk, 41 pages, tables, plates, 15 × 23 cms. Washington, Government Printing Office, 1935. Price ten cents. Technical Paper 563, A Study of Mine Roof in the Coking District of Western Pennsylvania, by J. W. Paul and L. N. Plein, 34 pages, tables, illustrations, 15 × 23 cms. Washington, Government Printing Office, 1935. Price five cents.

National Geographic Society, Contributed Technical Papers, Stratosphere Series No. 1, U. S. Army Air Corps Stratosphere Flight of 1934 in the Balloon

"Explorer," 122 pages, illustrations, tables, 17 × 25 cms. Washington, Society, 1935.

Canada Department of Mines, Mines Branch, Investigations in Ore Dressing and Metallurgy, July to December 1933. 194 pages, tables, 16.5 × 24.5 cms. Ottawa, King's Printer, 1934.

Canada Dominion Bureau of Statistics, Manufacturing Industries of the Prairie Provinces, 1933. 53 pages, tables, 21.5 × 28 cms. Ottawa, King's Printer, 1935.

National Advisory Committee for Aeronautics, Technical Notes No. 527, Strength Tests of Thin-Walled Duralumin Cylinders of Elliptic Section, by Eugene E. Lundquist and Walter F. Burke, 23 pages, tables, illustrations. No. 528, Wind-Tunnel Tests of a Cyclogiro Rotor, by John B. Wheatley and Ray Windler, 11 pages, illustrations. No. 529, Analysis of a Strut with a Single Elastic Support in the Span, with Applications to the Design of Airplane Jury-Strut Systems. Part I—Derivation of Formulas, by A. Murray Schwartz. Part II—Experimental Investigation of Formulas, by Reid Bogert, 60 pages, tables, illustrations. 3 pamphlets, 20 × 26 cms. Washington, Committee, 1935.

CURRENT TOPICS.

Dust Storms.—The *Oil and Gas Journal*, Vol. 33, No. 49, contains a very interesting account on the transporting of dust by the atmosphere. Following the drought of 1934 and the spring of 1935 there have been numerous dust storms in the west. Some of this dust has actually been observed in eastern cities and one report states that European countries have identified some of the dust as originating in the western part of the United States. The conditions that have brought about these dust storms date back to the period when prairie soil was broken for farming and the natural grass destroyed. The grass served to hold the top soil together and resist wind erosion. As long as the land yielded crops and there was sufficient moisture, dust storms were not severe. Lone periods of little or no rainfall permitted this top soil, made up largely of clays and volcanic ash, to pulverize completely when dried out.

The general term loess has been applied to the deposits of this dust blown material, but while loess is usually a wind deposit a very similar material develops from water deposition. It varies greatly in chemical composition.

R. H. O.

The New Haven's "Comet."—Recently there has been delivered to the New York, New Haven and Hartford Railroad an articulated three car, high speed streamline train to be known as the Comet. An excellent description of it appears in *Railway Age*, Vol. 98, No. 17.

The Comet is the first American built train with Diesel power plants at both ends. It is to furnish rapid and frequent transportation between Boston and Providence, a distance of 43.25 miles, and its schedule calls for five round trips daily, 44 minutes in each direction. The train has three body sections carried on four trucks, is 207 ft. long and weighs approximately 253,300 lbs. The structural feature deviates from standard car construction principles in that, for one thing, it is constructed as a tube with flat sides and well arched roof and bottom and with shear and compression stresses absorbed by the outer sheets.

The power plants are identical, each consisting of a six-cylinder 400 hp. Diesel engine and generators designed by Westinghouse. Each engine drives a main and an auxiliary generator which supply power for the operation of traction motors and auxiliary apparatus

throughout the train. The Comet is air conditioned by a Westinghouse system having 14 tons refrigeration capacity. Two Freon compressors are driven by direct-connected D.C. motors of 12 hp. each.

The trucks on the Comet are a departure from the conventional design in that shock absorbers which combine hydraulic and mechanical action have been substituted for the customary arrangement of elliptic springs between the bolster and truck frame.

R. H. O.

Protecting the Consumer.—A recent report of the Federal Food and Drug Administration indicates that many compounders of quack medicines and packers of food products still believe "what the public does not know will not hurt it." A fine of one thousand dollars has been assessed against the maker of Sayman's Healing Salve, Sayman's Vegetable Wonder Soap and Sayman's Liniment. The salve, composed of camphorated petroleum jelly, zinc oxide and boric acid, was offered as a treatment for eczema and other skin diseases, chronic old sores, and ulcers of the nose, throat, lungs and stomach. The soap, made from vegetable oil, was to be used along with the salve in its external use. The liniment was a mixture of red pepper extract, camphor, sassafras oil, chloroform, alcohol and water, but the labels claimed it to be a remedy for rheumatism, kidney diseases, pleurisy, tuberculosis, grippe, toothache, croup, cramps, hay fever, earache, deafness, ulcers, snake bite, horse colic and whooping cough.

Many food products also are discovered to be substandard or fraudulently labeled. For instance, "Cereal Meal" was found to be a mixture of bran and other wheat products, linseed meal and agar agar. Canned oysters have been found to contain excess brine; cider vinegar was made up of dried apple extract and acetic acid; sour cream contained added gelatine; and three varieties of "cheese" had been built up with mineral oil which is not a food.

C.

New Uses for Carbon Black.—An illustration of the mutual advantage sometimes accruing to Fellowships that run concurrently may be found in the Director of Mellon Institute's Twenty-Second Annual Report covering the activity of the Carbon Black Fellowship sustained by the Columbian Carbon Co. Thus, it has been discovered that the addition of 2 to 5 per cent. carbon black to sulfur-sand compositions improved markedly the workability of the mixtures and furthermore increased very appreciably their strength and stability. In fact the strength of certain sulfur cements

containing 2 per cent. carbon black was found to be as much as 50 per cent. greater than the strength of the same cement without the carbon black.

Also, various physical tests on concrete containing 2 per cent. dispersed black showed in every instance improved strength, this improvement being as much as 25 per cent. in some cases. Undoubtedly, the colloidal black besides coloring the concrete improves, in some manner, the bond between the hydrated cement and aggregate. It may be that these aqueous dispersions of carbon black will have a considerable use for increasing the strength of all compositions such as concrete, mortars and artificial stone.

C.

An Improved Electrothermic Instrument.—P. M. LINCOLN, in *Electrical Engineering* for May, 1935, describes this instrument for measuring watts, amperes, or volt-amperes. His treatment is on developments since his first paper to the A. I. E. E. in 1915, on this subject. In 1918, a second paper was contributed describing an electrothermic demand meter, which was soon adopted for use in Canada, and introduced in the United States, in 1928. The 1918 instrument has shortcomings that involve temperature error, power factor error, lack of uniformity, and lack of torque in the moving element. The present paper describes a construction eliminating these shortcomings. The instrument is actuated by the thermal expansion of a liquid in a closed system. Bourdon Tubes are used in pairs, the pairs being selected carefully, so that they have identical characteristics in so far as their response to temperature change and torque is concerned. The inside ends of a pair are attached to a common shaft so that the two tubes oppose each other; that is, one tube tends to rotate the shaft in one direction, and the other tube in the other direction. Capillary tubes are attached to reservoirs, which are heated by shunts and leads. The shaft of the instrument rotates when the two reservoirs are at different temperatures. The new instrument has a linear in-put deflection characteristic, and its time period may be adjusted readily to any desired value up to at least sixty minutes.

R. H. O.

New Sulfur Cements.—DIRECTOR E. R. WEIDLEIN, in his Twenty-second Annual Report on progress at Mellon Institute, reviewed the work of the multiple industrial fellowship sustained by the Texas Gulf Sulphur Co., Inc. During the past year announcement was made that acid-resistant cements formed by combining sulfur with an aggregate, could be improved by the

addition of certain olefin polysulfides. With the aid of these sulfides, sulfur cement can be made resistant to deterioration by fluctuating temperatures and can also be produced in varying degrees of plasticity. Such cements can be applied as bonding agents or as protective coatings in structures subjected to acids or corrosive solutions.

The Stevens Family.—To read of the activities of scientific men of the past, when handicaps to accomplishment were almost insurmountable, fills one with wonderment. In its early history our country was fortunate indeed, in having men of wealth, education and foresightedness, who had the ability to overcome many obstacles and lay the foundations for the enjoyment of future generations. In *Stevens Indicator* for May, 1935, Dean Franklin DeRonde Furman of the Stevens Institute of Technology, narrates an interesting account of the third John Stevens. Known as Colonel Stevens, he was born in 1749, and came to Hoboken, N. J., in 1783. Probably the most spectacular of his activities began in 1804, when he had built a steam screw boat, the "Little Juliana," with the first screw propeller and operated it between the Battery in New York and Hoboken. About 1805 he proposed a bridge from Hoboken to the Upper Battery. In 1816 he proposed the laying of a vehicular tunnel, not under, but in the beds of the Hudson and East Rivers, and drew plans to show how it could be done. His newly built steamboat "Phoenix," in 1809, was the first steamboat to ply the open sea. Beginning with the year 1813, Colonel Stevens and his sons Robert L. and Edwin A., the latter founder of the College, contributed much toward naval construction. The work of Colonel Stevens, relating to the early development of railroads, is well known. In 1851 John Cox Stevens, another son, as commander of the yacht "America," won the famous "America Cup" which, despite many efforts of English yachtsmen, has remained continuously in this country to the present day. In the present day of specialization, we are liable to forget the versatility of the founders of our country. R. H. O.

Dust Storms in Other Lands.—According to the United States Weather Bureau, this country does not have a monopoly upon dust storms—far from it. One of the most remarkable dust falls in history resulted from a great storm which raged over the dry steppes of southern Ukraine in 1928, blowing up such dense clouds of dust that day was turned into night. It was estimated that 15,400,000,000 tons of earth were swept up from the soil.

In March 1901 heavy dust storms occurred in the deserts of

southern Algeria. A cyclonic storm sucked up dust and deposited it over an area extending as far as 2,500 miles from the place of origin. In 1902 a dust storm swept nearly the whole of Australia and the surrounding ocean as far away as New Zealand. At many inland towns the darkness produced almost equaled that of the blackest night and in the houses nothing could be done without lamps or other means of lighting. Added to this were some phenomena of an even more terrifying character. At Boort and in some parts of the Riverina the storm was accompanied by a sort of globular lightning and "fireballs" were seen falling on the fields and roads.—Electrical displays in the form of brush discharges (St. Elmo's fire) are not uncommon in connection with our American dust storms. C.

A New Air Filter.—A well-known radiator manufacturing concern has announced a new corrugated fiber board air filter, of the replacement type especially designed to give uniform resistance and efficiency, thus reducing power costs in air conditioning apparatus. The filter is composed of two wafers of the corrugated fiber board placed together so that the cellular passages in the two boards, which are cut at a 45° angle, form a V-shaped passage with a 90° angle in it. These angles cause the air flow to change direction twice and scrub along the sides of the passages.

The entire filter is coated with a special compound that saturates dust, catching it in the filter. Each dust particle as it is saturated becomes a medium for catching other dust thus insuring long life for the filter. The coating will not become rancid, remains tacky at − 10° F. and will not drip at 180° F. Three models of the filter are offered, each one especially fitted to a certain type of conditioning unit. The difference lies in the diameters of the air passages. C.

A Low Melting Alloy.—At a recent convention of the American Chemical Society, SIDNEY J. FRENCH described a new quinternary eutectic of bismuth (41 per cent.), lead (22.1 per cent.), tin (10.6 per cent.), cadmium (8.2 per cent.) and indium (18.1 per cent.). This alloy melts at 116.4° F. and freezes at 116.0° F. The cost of the alloy at the present price of indium will range from $2.50 to $5.00 per ounce. The additions of small amounts of mercury or thallium will lower the melting point still further. An alloy composed of the first four metals of the five just listed has been known variously as Lipowitz Alloy or Wood's Metal. Its melting point is somewhat higher than the indium-containing counterpart, it being 161.0° F. C.

Clean Air Electrically.—(*Heat. & Vent.*, Vol. 32, No. 6.) The Westinghouse Company now have several experimental models of electrical units installed in Pittsburgh homes for the removal of dust, soot, pollen or other solid and liquid particles from the air. The unit is so arranged that it draws particle-filled air past two small wires suspended horizontally. Connected to a power pack, which raises their voltage, these wires "charge" all air particles in their vicinity. This act is termed ionizing the air. Next the ionized particles are drawn through a series of plates which are charged in opposite polarity with the result that the air particles cling to the plate. In addition, a film of oil covers each plate to make certain that the particles will stick after being attracted. After the aluminum plates fill up, they may be cleaned by simply running water over them. The air, freed of particles, is then sent on into the room by means of a fan. The unit only requires about fifty watts to operate. In certain sections of Pittsburgh, 97 per cent. of the impurities collected was in the form of soot. In outlying sections, the larger percentage of particles consisted of various irritating pollens. Data are being gathered by physicians in treating patients afflicted with asthma or the pollen fevers.

R. H. O.

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